ANNUAL INDEX
VOL. IX, 1959—p. 469

Forest Products Journal

Vol. IX, No. 12 December, 1959

Photo by R. B. Russell, U. S. Forest Products Laboratory

New Polyethylene glycol—1000 Treatment Produces Check-Free Walnut Gunstocks

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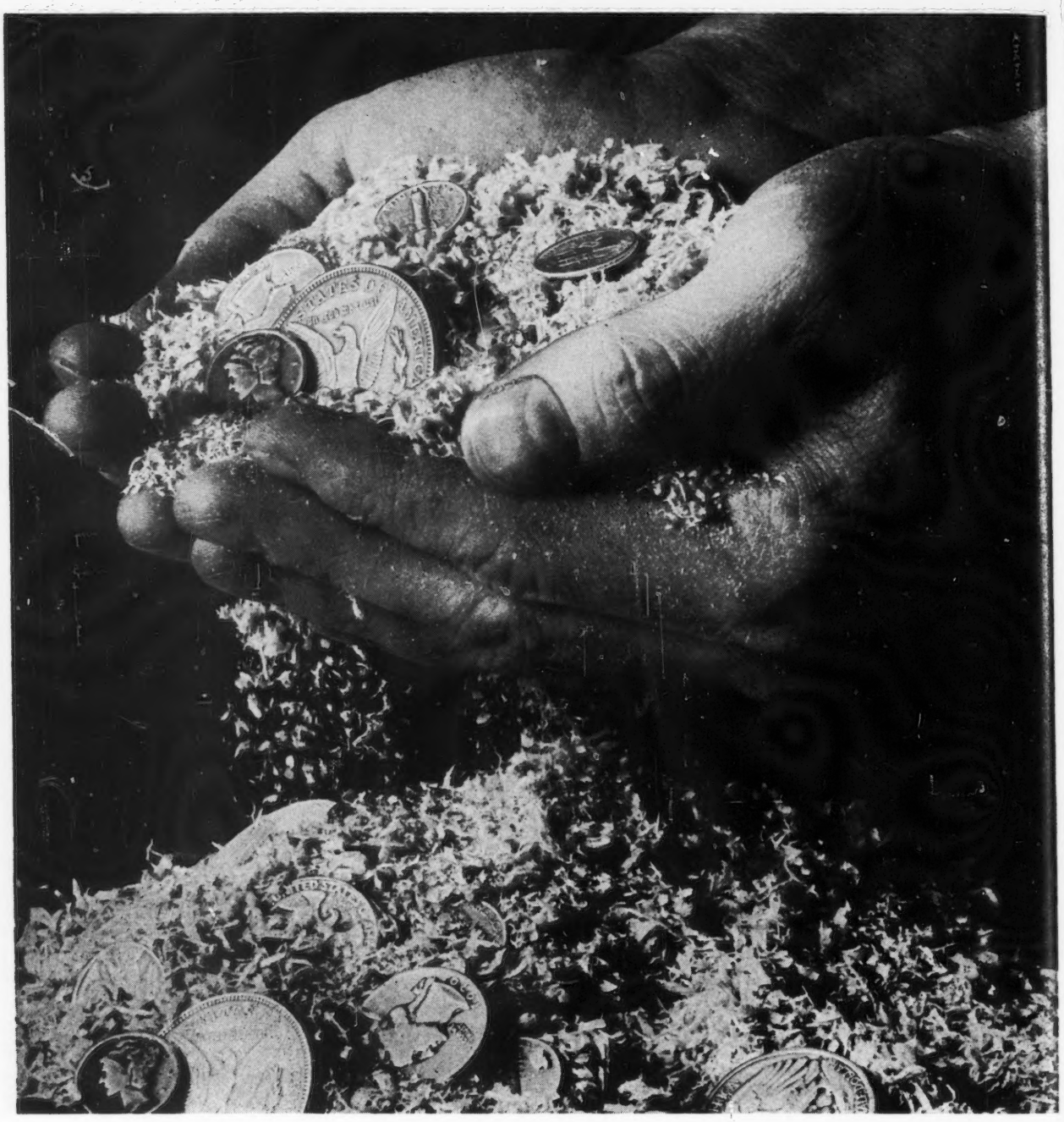

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FOREST PRODUCTS JOURNAL

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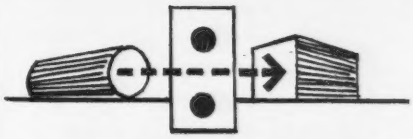

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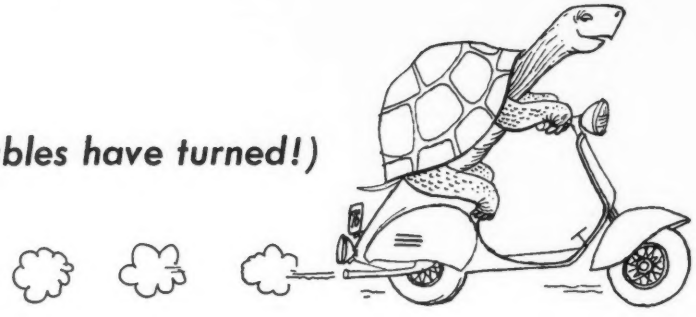
Have you heard this one about the Tortoise and the Hare?

(or: how the tables have turned!)



Of course you know the old fable about the tortoise and the hare . . . the rabbit was so confident he'd win that he took a siesta under a tree — and old "slow but steady" turtle won the race.

But that *is* a fable when it comes to wood furniture — because "slow but steady" isn't good enough for today's furniture manufacturer whose profits can be made or lost in his cost accounting. What his manufacturing methods and his furniture products *really* require is the slogan "fast but steady".

Take glue-setting for example. In core binding, joint assembly, edge bonding, veneering, etc., furniture-in-the-making used to have to spend a turtle-slow period of time standing stiffly in clamps, before taking the next step. A real bottle-neck — or, may we say, turtle-neck!

But now, along comes RCI 9153 PLYAMUL — and lo! What a difference! This easy-to-apply PVAc resin sets so quickly and effectively that clamping and hours wasted waiting for glue to dry are no longer necessary. Production lags are eliminated. Plant efficiency is markedly improved. Production proceeds at a steady pace . . . *"fast but steady"!*

For no fables, but some facts, you may be interested in writing to Reichhold for *Technical Bulletin G-11* on RCI 9153 PLYAMUL. This quality Reichhold product may not multiply your profits like rabbits — but will speed up that turtle-like production step when time is money.

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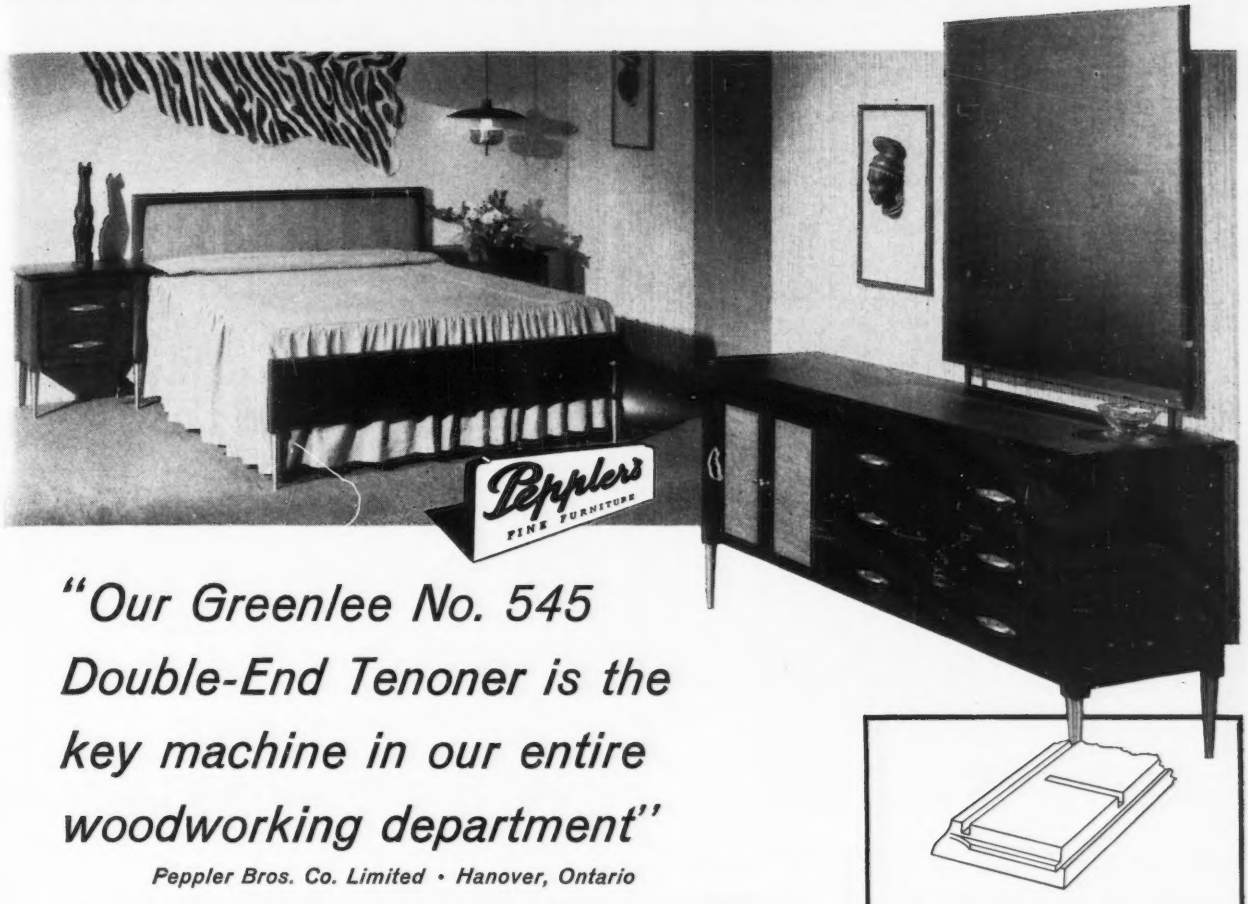

"Our Greenlee No. 545 Double-End Tenoner is the key machine in our entire woodworking department"

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A most beautiful and distinctive bedroom suite, Celestial, by Peppler Bros. Co. Limited of Hanover, Ontario, is shown above. Fluid, sculptured lines . . . cane panels . . . Alpine Walnut finish capture the light spirit of modern furniture at its best. For five years a Greenlee No. 545 Double-End Tenoner has been in continuous use at Peppler Bros. with no major breakdown or time loss. Machining handled by the tenoner includes serpentine-shaping, dadoing, relishing and vein-lining. One of the most complicated parts is the bar bed shelf handled in two operations . . . (1) rip and shape, groove for bar doors and rabbet for back panel; (2) cut-off, tenon, jump dado and relish. These two passes complete the major machining on the bar bed shelves and save five handlings usually required when using single purpose machines. Operation is extremely accurate . . . tolerances of .005" or better are maintained on long runs. Let us show you how the Greenlee No. 545 Double-End Tenoner can cut machining time and costs in your plant. Write for complete information.

Bar bed shelf is machined in two operations. Includes ripping, shaping, grooving for bar doors, rabbeting for back panel, cut-off and tenoning ends, relishing and jump dadoing.

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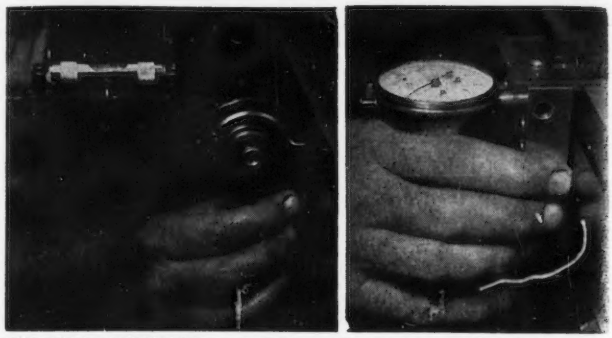

TWO NEW INSTRUMENTS, a precision angle indicator and horizontal opening indicator, eliminate "rule of thumb" methods for setting the angle of the knife and the horizontal opening between knife edge and nosebar on veneer lathe or slicer.

SINCE introducing these 2 new tools for precision cutting of veneers in January, they have been ordered and put into use in both softwood and hardwood veneer plants in every section of the U. S. and Canada — from British Columbia to South Carolina, from California to Ontario.

At a recent meeting one producer observed, "It doesn't make any difference how experienced the operator, there comes a time when he gets into trouble for some reason or other and he just can't get back. If he has some standards such as these instruments, they would help him correct his trouble."

With these instruments, even a novice can make accurate adjustments on lathe or slicer and cut good veneer consistently.

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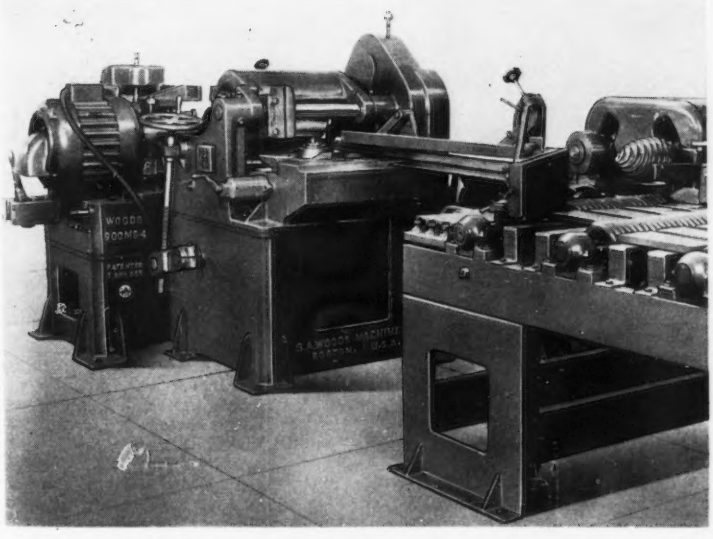
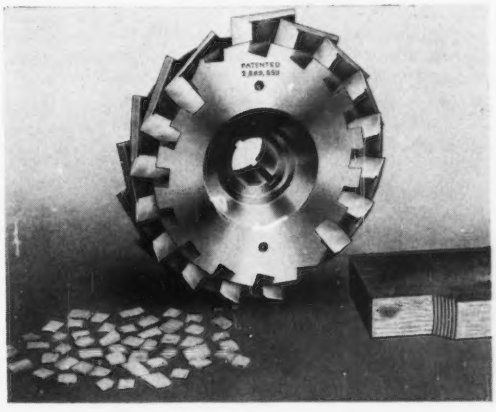
The Woods 900 MS Series Flaker–Surfacer introduces a new concept of wood working machinery to effect a more profitable utilization from stock being processed.

From the excess material of the rough lumber to be finished, this machine will produce wood flakes instead of sawdust and planer shavings. The size of the flakes can be varied to meet the demand.

These wood flakes contain the strength properties and desired fibre length of the wood to make them a very valuable raw material for the pulp, paper and composition board industries.



Woods 900 MS Series Flaker–Surfacer shown set up with automatic feed table and located ahead of planer and matcher or surfacer. Stock can be properly processed with this combination at speeds to 1000 linear feet per minute.



Flaker head is equipped with multiple radial knives arranged in a unique helical-spiral knife line. The knives cut parallel with, but in a special arc across the grain, removing the excess wood in uniform, longitudinally grain spiral end flakes, leaving a flat surface on the stock for final finish by the planer knives.

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FPRS News-Digest

Important FPRS Dates

January, 1960: FPRS National Executive Board, Chicago, Ill.
February 8–9, 1960: Northwestern Section Meeting, Bellingham, Wash.
March 24–25, 1960: Northeastern Section Meeting, Hartford, Conn.
June 5–9, 1960: Fourteenth National Meeting, Montreal, Canada.

Talk on "Forest Products in Russia" to Highlight Pacific Northwest Section Meeting Feb. 8-9

One of the highlights of the Pacific Northwest Section Meeting, which will be held in Bellingham, Wash., Feb. 8–9, will be an illustrated talk on "Forestry and Forest Products in Russia," by R. J. Seidl of the Simpson Lumber Co. As a member of a team of American foresters and technologists, Mr. Seidl recently completed a 30-day tour of Russia's forest industries.

The meeting will also include two technical sessions and two field trips. According to Bill Francis, Program Chairman, the technical sessions will be based on the theme "new laboratory methods of evaluation and new mill processes."

The field trips have been arranged by E. W. Wellwood. They will include trips to a laminating plant, a manufacturer of molded fiberglass pleasure craft, and a pulp mill. The pulp mill facilities also include an alcohol plant, a converting plant, and various processes that use sulfite waste liquor as the base material.

Chairman Francis has requested members to make their own hotel reservations. In addition to the Doric Bellingham Motor Hotel, where the meeting will be held, he pointed out that the Leopold and several motels offer fine accommodations.

PROGRAM

Monday, February 8, 1960

A. M.

8:00—Registration (Bellingham Hotel)

8:30—Leave hotel for tour of Brook Lumber Co. and Bell-Buoy Bo Co. Bus transportation will be pr vided.

P. M.

1:30—Technical Session No. 1

1. "Evaluation of The Effects of Direct Oil Fired Drier Upon th Glue Line Quality of Cold Pres Interior-type Plywood," Georg Sisterherm, Research Technolo gist, Douglas Fir Plywood As sociation.
2. "Heating Veneer Bolts for the Production of Douglas Fir Ply wood," John Lutz, Technologist U. S. Forest Products Laboratory Madison, Wisconsin.
3. "Microscopic Identification of Under-cured Hot Press Phenolic Resin Plywood Bonds," W. V. Hancock and P. L. Northcott, Vancouver Laboratory, Forest Products Laboratories of Canada (Presented by W. V. Hancock).
4. To be announced.

4:30—Business Meeting—Election of New Officers

6:00—Social Hour

7:00—Dinner Banquet "Forestry and Forest Products in Russia," R. J. Seidl, Simpson Timber Company.

Tuesday, February 9, 1960

A. M.

9:00—Technical Session No. 2

1. "A Survey of the Permeability of Douglas Fir in Oregon," Donald Miller, Oregon Forest Products Research Center, Corvallis, Oregon.
2. "Data Handling Techniques for Particle Board and Hard-Board," Dr. Murray Carroll, Western Operations Laboratory, Border Chemical Company.
3. "The Application of Confidence Limits to Plywood Bond Quality Test Results," James A. Klein Assistant Manager, Technical Service, Pacific Northwest Division, Reichhold Chemicals, Inc.
4. To be announched.

P. M.

1:30—Leave hotel for tour of Bellingham Shipyards and the Puget Sound Pulp and Timber sulfite mill, including the Pacific Coast Paper Mill Division. Transportation by private automobile planned.

We—the Staff at your National Executive Office—extend our warm and heartiest wishes that all of you experience a most pleasant and a most prosperous New Year.

Arthur Heim, publication sales and advertising records; Frank J. Rovsek, executive secretary; Mrs. Marian Evers, stenographer; Miss Mary Sharkey, membership records; Mrs. Janice Brunsell, bookkeeper; Mrs. Claire Joyner, editorial assistant; and John K. McDonald, editor.

Third Annual Kiln-Drying Short Course March 21–25, 1960

K. R. Peterson, wood technologist at the University of Illinois, announces that the Department of Forestry will act as host for the 1960 Kiln-Drying Short Course, which will be conducted cooperatively with the following agencies: Delmhorst Instrument Company, Foxboro Company, Iowa State University, Lumber Drying Specialty Company, Michigan State University, Moore Dry Kiln Company, Purdue University, Standard Dry Kiln Company, Southern Illinois University, University of Michigan and the Wel-Dri Company.

This five-day course in kiln drying and seasoning of wood is unique in that it combines the resources of a number of educational institutions and industrial firms. Major emphasis is placed on the practical aspects of seasoning. For further information, write, Kiln-Drying Short Course, Department of Forestry, 219 Mumford Hall, Urbana, Illinois.

LSU Forestry Symposium

Louisiana State University's ninth annual Forestry Symposium will be held April 6 and 7, 1960. Topic for the meeting is "The Use of Chemicals in Southern Forests." The discussion will include chemical usage in forest protection as well as fertilization and herbicides. Inquiries should be addressed to Prof. Robert W. McDermid, LSU School of Forestry, Baton Rouge 3, La.

SECTIONS *in the NEWS*

105 persons registered for the Fall Annual Meeting of the Carolinas-Chesapeake Section, held at the Hickory Elks Club, Hickory, N. C., November 12 and 13. The Executive Secretary, Frank J. Rovsek, and Mrs. Rovsek, Madison, Wis., were privileged to be in attendance.

FPRS President E. S. "Scotty" Harrar and Mrs. Harrar were guests of honor at the meeting held in their 'home' Section. L. to r., Walt Smith, Southeast Region Board Member; Scotty Harrar; outgoing Section Chairman, Ken Redman; and Past National President Roy Carter.

Among the speakers are, John Whiteside, the Lilly Company; Section Secretary George Smith, North Carolina State College; William Kyle, E. I. DuPont Company; and Dr. A. J. Stamm, North Carolina State College.

L. to r., Maury Rhude, Unit Structures, Inc., Peshtigo, Wisconsin; Walt Smith, Asheville, N. C.; Rufus Page, U. S. Forest Service, Asheville, and a guest.

Research News from Forest Products Labs of Canada

Sawmill Courses

F.P.L. of Canada in continuing its program of sawmill courses dealing with the small circular sawmill have recently completed three successful courses in Western Canada. Subject matter was based to a large extent on the findings of studies carried out at the FPLC Research Sawmill and on data ob ained through field studies at co-operating sawmills. Subjects covered were mill installation, power requirements, production control, seasoning, planing mill losses, waste utilization and management.

Strength and Related Properties of Woods Grown in Canada

FPLC has issued a revised version of the chart E-113 tables, Technical Note "The Strength and Related Properties of Woods Grown in Canada". Besides incorporating the latest test data on all Canadian woods, Technical Note No. 3 differs from Chart No. E-113 in that all of the strength values for air-dry woods have been adjusted mathematically to a uniform moisture content of 12 per cent. This makes comparisons of the strength of different species considerably easier. It will be noted that in presenting the strength values for Douglas fir, the earlier distinction between coast and mountain has been dropped. Copies are available, on request, from the Forest Products Laboratories of Canada, at Ottawa or Vancouver.

End Staining of Veneer Logs

A problem encountered in the hardwood plywood industry is the development of a discoloration in the wood at the ends of veneer bolts. This discoloration, or stain, may extend in several inches or more from the ends of the bolts and result in serious degrade in large quantities of veneer.

An analysis of such material indicated a high concentration of iron in the stained areas as compared to normal wood. The results indicated that this contamination could only have occurred while the logs were stored in ponds or in log cooking vats. Where this problem occurs it is recommended that the water used in the ponds and cooking vats be checked for iron content. Where the iron content is found to be excessive, i.e., several times greater than that of the local water supply, the necessary steps can be taken to remove the cause of the trouble.

Radioactive Tracers

In the Ottawa Laboratory radioactive chlorine, incorporated in the wood preservative pentachlorophenol, is being used to study the difficult problem of penetration of solutions through wood. It is of great importance in wood preservation to have fast and reliable analytical methods for the determination of small quantities of preservatives in treated material. When isotopically labelled pentachlorophenol solutions are used, radioactivity readings from minute shavings taken from the various treated parts are sufficient to determine quickly and precisely the amount of preservative present since the preservative density is proportional to the level of radioactivity found in the sample. It is conceivable that future inspections for the presence of sufficient preservative in such important items as telephone poles, piling and railway ties will be carried out simply by bringing a Geiger counter in contact with the wood.

Effect of Wood Moisture Content on Gluing

A new 16 page publication, Technical Note No. 12 titled "Effect of Wood Moisture Content on Gluing" has been issued. This deals with such subjects as: the dimensional changes in wood with changes in moisture content and their significance as related to glued wood products; the part played by moisture in wood in a gluing operation and the nature of defective joints.

EDITORIAL CORRECTIONS

The October issue of the JOURNAL contained an article by I. A. Pearl and D. L. Beyer entitled "Separating Lignosulfonates from Carbohydrates in Aspen Spent Sulfite Liquor by Ion Exchange." Tables 1 and 2 were inadvertently omitted from the article; therefore, they are printed below.

The same issue contained an article by C. W. McMillin and J. L. Lubkin entitled "Circular Sawing Experiments on a Radial Arm Saw." Inadvertently, the abstract used was not based on the final version of the abstract submitted by the authors. In addition, four curves—similar in appearance but demonstrating significant technical differences—were transposed. The curves with the correct figure titles are on the next page.

We extend our apologies to the four authors and to our readers.

Separating Lignosulfonates from Carbohydrates in Aspen Spent Sulfite Liquor by Ion Exchange

Table 1.--FRACTIONATION OF DECATIONIZED ASPEN SPENT SULFITE LIQUORS ON ANION-EXCHANGE RESINS

Expt. no.	Starting liquor: Decationized liquor	Starting liquor: Total solids, g.	Starting liquor: MeO, g.	Anion-exchange resin[1]	Effluent: Total solids, g.	Effluent: MeO, g.	NaOH eluate: Total solids, g.	NaOH eluate: MeO, g.	Combined fractions: Total solids, g.	Combined fractions: MeO, g.	Combined fractions: Recovered MeO, %	Separation,[2] %
1	I	34.6	3.28	Du A-6	11.2	0.38	31.0	2.13	42.2	2.51	76.5	85
2	I	42.4	4.0	Du A-7	18.6	1.19	17.3	1.79	35.9	2.98	74.5	60
3	I	42.4	4.0	Du A-70	24.3	2.30	23.4	0.88	47.7	3.18	79.5	28
4	I	17.3	1.64	Du A-2M	5.4	0.10	16.5	1.21	21.9	1.31	80.0	92
5	II	21.2	2.0	Du A-101	16.8	1.62	7.4	0.04	24.2	1.66	83.0	2
6	I	21.2	2.0	Du A-102	14.7	1.73	8.1	0.04	22.8	1.77	89.0	2
7	I	21.2	2.0	Am 400	11.6	1.59	11.0	0.05	22.6	1.64	82.0	3
8	I	21.2	2.0	Am 401	15.4	2.00	10.9	0.08	26.3	2.08	104.0	4
9	II	45.0	4.0	Du A-6	14.5	0.64	36.0	2.63	50.5	3.27	81.8	80
10	II	45.0	4.0	Du A-7	16.0	0.93	29.8	2.36	45.8	3.29	82.2	72
11	II	45.0	4.0	Du A-70	25.0	2.40	27.8	1.76	52.8	4.16	104.0	42
12	II	22.5	2.0	Du A-2M	7.1	0.23	22.8	1.87	29.9	2.10	105.0	89
13	II	22.5	2.0	Du A-101	9.2	1.15	6.6	0.04	15.8	1.19	60.0	3
14	II	22.5	2.0	Du A-102	14.3	1.87	8.2	0.07	22.5	1.94	97.0	4
15	II	22.5	2.0	Am 400	12.5	1.56	12.4	0.11	24.9	1.67	83.5	7
16	II	22.5	2.0	Am 401	9.4	1.34	10.9	0.04	20.3	1.37	68.5	3

[1]Du = Duolite; Am = Amberlite IRA-

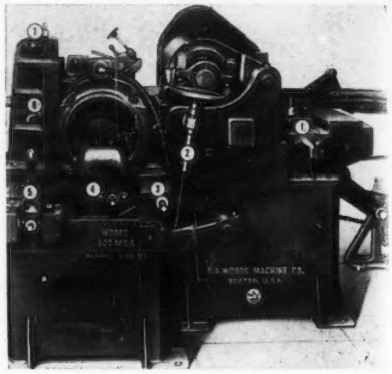
[2]Separations of lignosulfonate and carbohydrate materials are calculated from the ratio of methoxyl recovered in the sodium hydroxide eluate to the total recovered methoxyl.

Table 2.--ALKALINE NITROBENZENE OXIDATIONS OF FRACTIONS FROM FRACTIONATION OF DECATIONIZED ASPEN SPENT SULFITE LIQUORS ON ANION-EXCHANGE RESINS

Expt. no.	Starting liquor: [1]Syr., g.	Starting liquor: [2]Van., g.	Starting liquor: Ratio syr./van.[3]	Effluent: Syr., g.	Effluent: Van., g.	Effluent: Ratio syr./van.	NaOH eluate: Syr., g.	NaOH eluate: Van., g.	NaOH eluate: Ratio syr./van.	Total recovered product: Syringaldehyde, g.	Total recovered product: Syringaldehyde, %[4]	Total recovered product: Vanillin, g.	Total recovered product: Vanillin, %[5]	Total recovered product: Ratio syr./van.
1	2.74	1.42	1.42	0.34	0.29	0.98	1.70	1.06	1.33	2.04	75	1.35	95	1.26
2	3.36	1.98	1.42	0.79	0.66	1.00	1.59	0.97	1.37	2.38	71	1.63	82	1.22
3	3.36	1.98	1.42	1.47	1.33	0.93	0.86	0.44	1.58	2.33	69	1.77	89	1.09
4	1.37	0.71	1.42	0.12	0.09	1.11	1.09	0.70	1.29	1.21	88	0.79	111	1.28
5	1.68	0.99	1.42	0.95	0.75	1.08	0.08	0.08	0.83	1.03	61	0.83	76	1.03
6	1.68	0.99	1.42	1.05	0.98	0.92	0.03	0.03	0.83	1.08	64	1.01	102	0.89
7	1.68	0.99	1.42	1.00	0.80	1.00	0.07	0.06	1.00	1.07	64	0.86	87	1.03
8	1.68	0.99	1.42	1.16	0.96	1.00	0.10	0.09	1.00	1.26	75	1.05	106	0.99
9	3.15	2.30	1.17	0.43	0.35	1.03	1.98	1.14	1.45	2.41	77	1.49	65	1.35
10	3.15	2.30	1.17	0.59	0.53	0.92	2.05	1.27	1.35	2.64	84	1.80	78	1.23
11	3.15	2.30	1.17	1.57	1.31	1.00	1.76	1.17	1.26	3.33	106	2.48	108	1.12
12	1.58	2.30	1.17	0.22	0.22	0.83	1.01	0.86	1.08	1.23	78	1.08	94	0.95
13	1.58	1.15	1.17	1.26	0.92	1.17	0.06	0.06	0.83	1.32	84	0.98	85	1.13
14	1.58	1.15	1.17	0.95	0.86	0.92	0.05	0.05	0.83	1.00	63	0.91	79	0.92
15	1.58	1.15	1.17	0.98	0.73	1.17	0.06	0.05	1.08	1.04	66	0.78	66	1.11
16	1.58	1.15	1.17	1.09	0.82	1.08	0.09	0.05	1.33	1.18	75	0.87	76	1.13

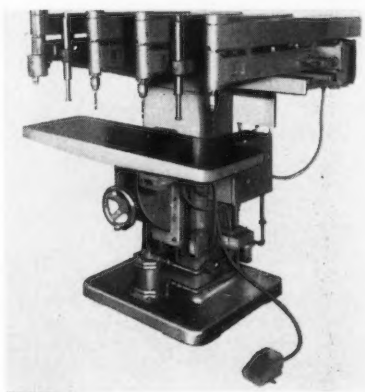
[1]Syr. = syringaldehyde
[2]Van. = vanillin
[3]The ratio of syringaldehyde to vanillin is on the molar basis.
[4]The % syringaldehyde is based upon the syringaldehyde obtained from the original decationized liquor.
[5]The % vanillin is based upon the vanillin obtained from the original decationized liquor.

NEW PRODUCTS and Literature



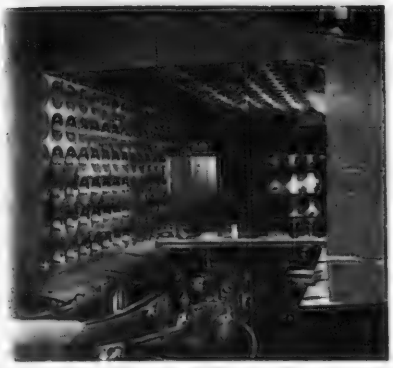
New Woods Flaker–Surfacer

S. A. Woods Machine Co., Boston, 27, Massachusetts, has announced a new 900 Series Flaker-Surfacer which is designed to obtain more profitable utilization from stock being processed. From the excess material of rough lumber to be finished, the machine produces wood flakes in place of customary sawdust or planer shavings. The size of flakes can be controlled. Stock can be properly processed and salable flakes for pulp or board use derived at speeds to 1000 linear feet per minute. Write for Bulletin W–900.



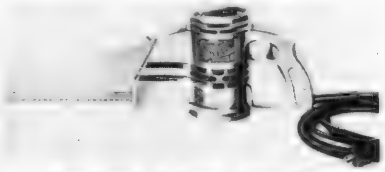
Improved Multiple Spindle Boring Machine

An improved Ekstrom–Carlson No. 448 Multiple Spindle Boring Machine is specifically designed for woodworking, to set up in minimum time. The air operated table lift is controlled by a foot valve. Upper rail will take 1 to 8 spindles. Spindle assembly has ball bearing spindle, geared chuck, pulley, cast iron frame, flat belt and 3600 R.P.M. motor with individual push button control station. By loosening two bolts assembly can slide over the rail to any position. Two models are available: with 48" rail to take 6 spindles or 72" rail to take 8 spindles. Write Ekstrom, Carlson & Co., 1400 Railroad Ave., Rockford, Ill.



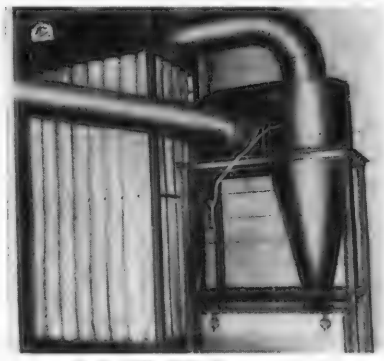
New Infra-Red Electric Oven

The first radiant oven in the furniture industry capable of handling a wide range of sizes and shapes is drying the final lacquer finish at the Louisville, Ky., plant of the Kroehler Furniture Mfg. Co. The ceramic type infra-red electric oven was built by the DriQuick Oven Div. of the Dry Clime Lamp Corp., Greensburg, Ind.



New Type of Power Hand Saw

A new concept in power hand saws has been announced by Wells Manufacturing Corp., 1415 Service Rd., Three Rivers, Mich. It is a power version of the hand saw. The manufacturer claims it provides the accuracy, versatility and convenience of the hand saw plus the speed and efficiency of a power tool. The reciprocating blade cuts on both forward and return strokes to provide 8000 1-1/8" cutting strokes per minute. Construction features include antifriction ball and needle bearings, head treated helical gears, specially designed heavy duty AC/DC motor, precision die cast housing and double pole switch that breaks both lines.



Dust Collecting Improvement

A new cloth tube, auxiliary filter has been announced by Aget Mfg., Co., Adrian, Mich. Designed for use with 3000 or smaller series Dustkops, it broadens the use of standard units. Unit F.T. 40 comes equipped with a simple manual shaking device so that tubes can be freed of collected dust at regular intervals. Ideal dust collecting units for operations where a high volume of fine dust or fine dust mixed with heavy dust which may not reach the filter is encountered.

Editorial Correction

Circular Sawing Experiments on a Radial Arm Saw

Abstract

Experimental results are presented giving the net power required to saw certain speciees of wood under a variety of cutting conditions. A 16-in. diameter, spring-set combination circular sawblade is used. The variables investigated include feed rate, species, depth of cut and cutting direction. For the case of flat-sawn hard maple, it is shown that a single power formula can simultaneously encompass the effects of depth of cut, feed rate and cutting direction, with good accuracy.

What This Research Means:

Machining processes must be examined with a critical eye to be economical at modern production rates. Wood is easier to machine than metals, but this is no reason to ignore the savings that can be effected by properly matching the tool to the work at hand.

As information of the type reported in this paper accumulates and is synthesized into handy form, we can expect that the task of the equipment designer and the wood machining specialist will be greatly simplified.

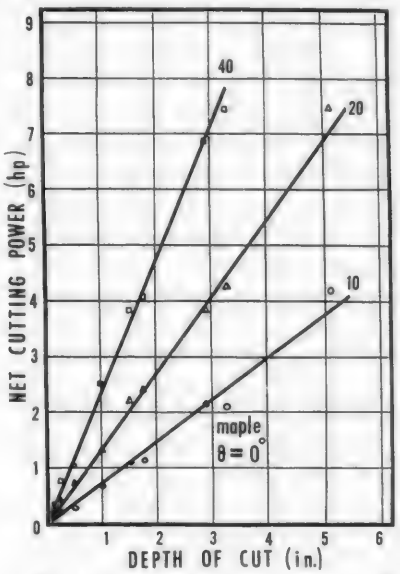


Fig. 9.—Net cutting power versus depth of cut for three feed speeds. Numbers next to curves give feed speed in fpm.

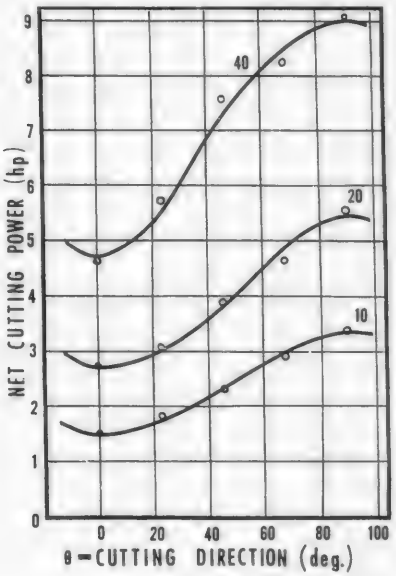


Fig. 14.—Net cutting power versus cutting direction (Θ) for three feed speeds. Numbers next to curves give feed speed in fpm.

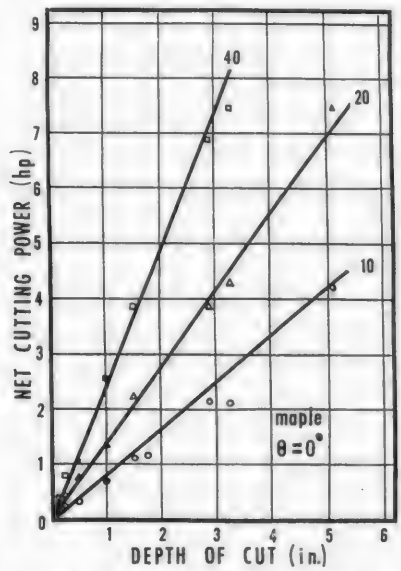


Fig. 15.—Diagram for evaluation of curve-fit: net cutting power versus depth of cut for three feed speeds in fpm. The lines are drawn from Eq. (7). Original test data are also shown.

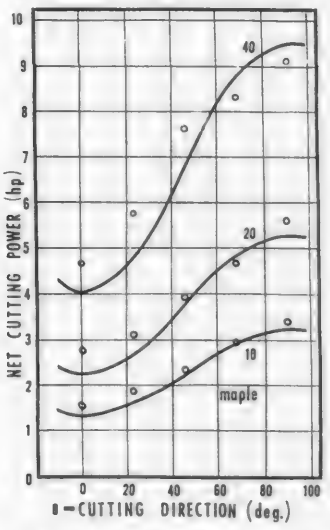
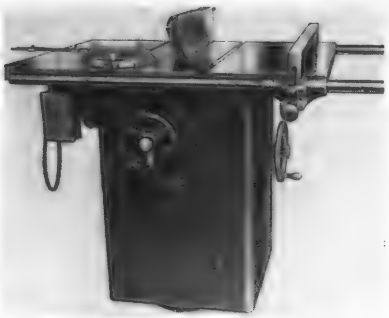
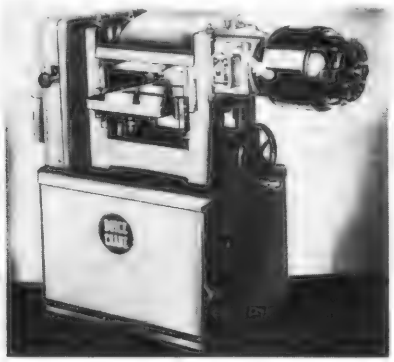


Fig. 16.—Diagram for evaluation of curve-fit: net cutting power versus cutting direction for three feed speeds in fpm. Curves are drawn from Eq. (7). Original test data are also shown.



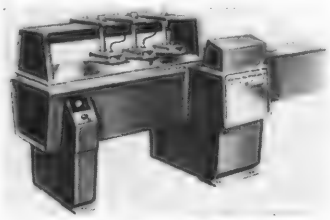
Powermatic 12" Tilting Arbor Saw

Powermatic Machine Co. announces an improved Model 70–12" Tilting Arbor Saw, now equipped with tubular guide bars, front and rear. A new rip fence incorporates features desired by users. Alignment of the fence with the table is accomplished by an adjusting screw in each side of the fence, to insure accurate ripping of stock. The front bar has an accurate vernier scale adjustment. The fence-hooking mechanism with front and rear control handles is conveniently located at the front of the fence.



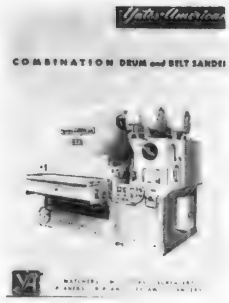
Planer with Chip Breaker

A combined chip breaker-deflector, featured on the new Boice–Crane 12" x 4" planer, also forms a complete guard for the cutterhead. Accelerated velocity, effected by flattening the trajectory, causes the chips to accumulate farther back to the work zone, thus precluding roll-in of chips. Linkage makes the work feed's initial lumber pickup automatic, rather than manual. Write Boice–Crane Co., 929 W. Central Ave., Toledo 6, Ohio.



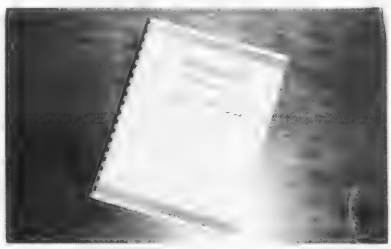
New Contour-Profiler

A production machine to take over most of the manually fed work of the hand shaper has been introduced by Onsrud Machine Works, Inc., 7752 Lehigh Avenue, Niles 48, Ill. It reportedly provides all the safety, efficiency, and speed of an automatic shaper with the simplicity and low cost of hand shaper forms. The machine is built in two models, one for parts up to 48" long and the other for parts up to 72" long.



Combination Belt and Drum Sander

Bulletin No. 53 provides specifications on the Yates–American Model S–53 Combination Belt and Drum Sander. Features include: both belt and drum sanding in one pass . . . . stock that varies in thickness . . . . extra fine finishes . . . belt speeds to 6000 FPM . . . feed rates to 90 FPM . . . takes stock from 10" to 55" wide and to 6" thick. Yates–American Machine Company, Beloit, Wis.



FPRS Wood Machining Abstracts

The Committee on recent wood machining literature, a sub-division of the Wood Machining Division, has compiled a 20 page report containing significant abstracts selected from world sources on the subject of wood machining. The purpose of these abstracts is to supply information whereby one may locate recent publications in the field. Section 1 contains a partial list of sources on wood machining subjects. Section 2 contains abstracts grouped by the general subject matter. The Committee is composed of: Charles W. McMillin, American Machine & Foundry Co.; Robert J. Hoyle, Potlatch Forests, Inc.; Norman C. Franz, University of Michigan; Lawrence Leney, University of Missouri; and Richard Perkins, Syracuse University. Single copies are available on request to: Forest Products Research Society, Box 2010, University Station, Madison, Wisconsin. Additional copies are available at 50¢ each.

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Inquiries concerning employment listings or ads to be placed in the JOURNAL should be addressed to FPRS Employment Service P. O. Box 2010, University Station, Madison 5, Wis. Correspondence is kept confidential.

Positions Offered

E–374—Experienced furniture factory engineer. Excellent opportunity for qualified man. Now producing medium-priced case goods, quality product. Your detailed letter will be held in strict confidence. (Dec.)

E–375—Wood technologist wanted for research and development by integrated forest products manufacturer in Central South. Master's degree in wood technology or composition board manufacturing or testing, wood utilization, with experience in wood desirable. However, will consider BS degree with demnostrated ability for research and development. (Jan.)

Employment Wanted

580—42 years of age, graduate of Amherst College, Massachusetts, and the Yale Forestry School, Connecticut. Experience primarily in procurement and purchasing of forest products. A shorter time spent in related field of corrugated board promotion and direct paper chemical sales for a New York City container-board association and a chemical company. (Dec.)

581—M.F. Dr. techn. sc. Married, 34 years old, with considerable background in the particleboard, fiberboard, molded products field. Seeks a responsible position in this field. Available 1960. (Dec.)

586—Production management or plant engineering and development in hardwood dimension or furniture industry. Ten years' experience: machine operation, custom kiln drying, plant and yard layout, materials handling, purchasing, inventory, administration. Last five years as superintendent of pilot plant for applied research in hardwood products and instructor in production wood-working program at a technical institute. B.S. Forestry, M.F. Wood Technology; age, 37; married, 3 children. Prefer East but will consider elsewhere. (Jan.)

587—Primary forest products research or production position with large wood manufacturing or wood using industry where there is opportunity for advancement. Experienced in forestry, wood drying, lumber drying research, and hard work. Have B.S. in Wood Technology from University of Michigan, and expect Master of Wood Technology in February. Veteran. Will work anywhere but general South. (Jan.)

FPRS FOREST PRODUCTS JOURNAL VOL. IX, NO. 12 DECEMBER. 1959

NEW CHEMICAL TREATMENT CURBS

Shrink and Swell of Walnut Gunstocks[1]

H. L. Mitchell and H. E. Wahlgren
Forest Products Laboratory,[2] Forest Service U. S. Department of Agriculture

Reduces shrinkage and swelling to less than thermal expansion of most plastics . . . Practically eliminates splits, checks, and other seasoning degrade . . . Reduces kiln time by about two weeks . . . Advantages for the rifleman—dimensional stability plus warmth and beauty of wood.

Basing their work on fundamental research by Dr. A. J. Stamm, the authors, H. L. Mitchell (seated) and H. E. Wahlgren, carried this program through research, laboratory, and pilot plant stages in less than 10 months. The work has been picked up by industry, and the stabilized gunstocks are being produced commercially.

A NEW CHEMICAL TREATMENT that imparts a high degree of dimensional stability to solid wood gunstocks has been developed by the U. S. Forest Products Laboratory. Rifle stocks machined from green walnut and treated with the chemical before they are kiln dried will, when seasoned, shrink and swell substantially less than untreated "control" stocks. Such chemically stabilized stocks are not apt to change sufficiently in dimension to throw a well-bedded barrel and action out of alinement, even when the rifle is exposed to extremes of temperature and humidity.

For best results, the chemical must be applied to the green wood fresh from the saw. Treatment of precarved stocks or stock blanks at this stage practically eliminates splits, checks, internal honeycomb, and other degrade during seasoning, and permits accelerated drying according to a kiln schedule far more drastic than that normally recommended for walnut gunstock blanks. Or, the treated wood can be air dried over a longer period with equally good results. Preliminary studies indicate that even highly figured woods like Oregon myrtle, curly bird's-eye maple, and some wild-grain tropical species—all known to be bad actors from the standpoint of tendency to split, check, and warp during drying—can be seasoned without significant degrade with this process.

The chemical used is polyethylene glycol–1000. The "1000" refers to the average molecular weight of this compound. It is a first cousin of permanent-type antifreeze, and is a member of a whole family of polyethylene glycols having varying molecular weights, solubilities, freezing and boiling points, and other properties. Polyethylene glycol-1000 is a white, waxlike chemical that resembles paraffin. It dissolves readily in warm water, is nontoxic, noncorrosive, melts at 104° F., and has a very high (580° F.) fire point.

Dr. A. J. Stamm, formerly on the staff of the Forest Products Laboratory, and now with North Carolina State College, pioneered the use of polyethylene glycols to restrain wood from shrinking and swelling.[3] He assisted in planning, and helped to start the work on gunstocks here described. Dr. Stamm's fundamental research in the

The Authors: Harold Mitchell is Chief of the Forest Products Laboratory's Division of Timber Growth and Utilization Relations; H. E. Wahlgren is a research technologist at the laboratory.

[1] A contributed paper received October 1959.
[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Stamm, A. J. 1959. Effect of polyethylene glycol on the dimensional stability of wood. For. Prod. Jour. IX (9): 375-381.

Stock and forearm blanks end coated, chemically treated, and kiln dried on accelerated schedule; and finished products fitted to Remington Model 11.

field of dimensional stabilization of wood has been widely published in various technical journals and reports. Processes based on his work are now used commercially, on a limited basis, in the manufacture of wood carvings, and in related industries.

Polyethylene glycol affects dimensional stability of wood by diffusing into and lodging in the fine structure of the fiber walls, where it provides a bulking action that restrains the walls from shrinking as they dry. For example, when a piece of wood is completely saturated with a 30 per cent aqueous solution of polyethylene glycol-1000, it does not shrink to appreciably less than its green dimensions even when air seasoned at low humidities for a long period, followed by oven-drying at 212° F. to a moisture-free condition. Neither will it swell appreciably when exposed to high humidities. By way of comparison, untreated walnut shrinks in volume an average of 12.8 per cent when taken from the green to the bone-dry condition. Under the same conditions, even-textured, straight-grained black cherry shrinks 11.5 per cent and hard maple 14.9 per cent. Highly figured woods, because of interlocked grain or other fiber distortions and abnormalities, normally shrink and swell even more than straight-grained specimens of the same species, and therefore have a greater tendency to warp, twist, and split during seasoning.

Description of Experiments

In the studies here reported, two fresh-cut walnut logs from a farm woodlot in the vicinity of Richland Center, Wis., were sawed into 2-½-inch-thick planks at the Dunston and Merry Mill at Richland Center. Immediately following sawing, the planks were transported to the Forest Products Laboratory, where 28 standard-size shotgun stock blanks were band sawn from them. The stock blanks, from carefully matched planks, were then divided into two groups.

Half of the green shotgun stock blanks were sealed in polyethylene bags, to prevent moisture loss, and stored in a conditioning room maintained at a constant 35° F and 82 percent relative humidity.

The other half of the green blanks were soaked for 39 days in a vat containing a 30 percent (by weight) aqueous solution of polyethylene glycol-1000 maintained at room temperature that averaged about 73° F. The chemical used was supplied by The Dow Chemical Company, Midland, Mich. Henry A. Huber of Dow's Technical Service and Development Department assisted in planning these and subsequent experiments.

Several control specimens of green walnut 2 by 2 by 8 inches in size were put in the soaking vat along with the gunstock blanks. These controls were used to check depth of penetration and amount of polyethylene glycol taken up by the blanks. About once a week, one of these specimens was removed from the vat, and a thin section was sawed out from near the center for quantitative analysis by a vacuum extraction method. Our objective was to get enough chemical into the wood to achieve marked improvement in dimensional stability in an economically feasible period of soak.

In another phase of the same experiment, eight standard-size rifle blanks were cut from the matched planks, sealed in polyethlene bags, and transported to the plant of the cooperating gunstock manufacturer, the Win–A–Mer Company, Waseca, Minn. There they were inletted for a Springfield action and machined to the Win–A–Mer custom sporter pattern to within approximately ⅛ inch of the desired finished dimensions. Then they were soaked in a 30 per cent polyethylene glycol-1000 solution for 24 days.

The precarved stocks are much smaller in diameter than the blanks, and inletting for action, barrel groove, and magazine box permits diffusion of the chemical into the wood from two sides. Therefore, it is possible to get sufficient chemical into the wood to achieve a high degree of dimensional stability, especially in critical areas, in a shorter period of soak than is required for the thicker blanks.

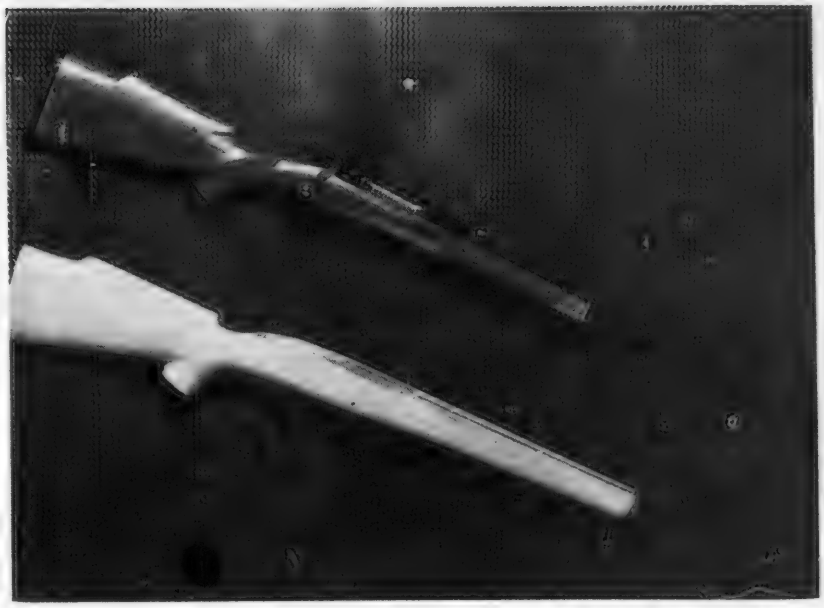
At the end of the soaking period, the chemically treated blanks and precarved stocks, together with the untreated blanks from cold storage, were accurately measured with a micrometer at several marked spots, and their green dimensions recorded. The treated and untreated blanks, and the treated precarved stocks, were then divided into two equal groups and placed in separate experimental dry kilns.

One kiln was operated according to the schedule normally used for drying

walnut gunstock blanks. This schedule was developed by the Forest Products Laboratory during World War II at the request of the Army for use in drying stocks for military small arms. It is described in detail in Forest Products Laboratory Report No. R1433. With this schedule, it took 57 days to reduce the moisture content of the blanks and precarved stocks from the green condition to an average moisture content of 6 percent, including 5 days at the end of the kiln run for equalizing and conditioning.

The other kiln was operated according to a schedule far more drastic than any heretofore recommended for commercial use. With this schedule, the moisture content of the green blanks and precarved stocks was reduced to 6 percent in only 44 days—13 days less than the normal kiln time for this sort of material.

At the end of the kiln runs, all blanks and precarved stocks were again micrometered at the same points at which their dimensions were measured in the green condition.



Precarved (from green wood), chemically treated, kiln-dried walnut stocks, one finished and fitted to sporterized Springfield M1903A3 and the other as it appeared when taken from the kiln. (Stock by Win-A-Mer Co., Waseca, Minn.; metal work by Rusk Gun Shop, Madison, Wis.)

Effect on Seasoning Degrade

All of the chemically treated precarved stocks came out of the kilns in excellent condition. There was no sign of surface checks, splits, or other defects, even on those dried according to the drastic schedule. About half of the stocks were sawed across the thick part of the butt midway between the toe and the pistol grip to check for internal honeycomb. No such defects were found. These findings are especially significant in view of the fact that the precarved stocks were not even given the usual end coating (a mixture of asphalt and coal-tar pitch) before they went into the kiln.

The results of these and later studies show that thick walnut blanks treated with polyethylene glycol can also be successfully dried by the drastic schedule used. However, with the thick blanks, which take longer to reach the same level of chemical treatment as the smaller precarved stocks, it is necessary to apply the usual end coating previous to chemical treatment and subsequent drying. End coating retards drying and also prevents development of a severe stress gradient between the heavily treated end grain and the interior fibers, which contain little or no polyethylene glycol, thus controlling the internal honeycomb that may otherwise develop.

As anticipated, the drastic kiln schedule proved too severe for the end-coated blanks that received no chemical treatment. Most of these blanks showed surface checks and splits as well as internal honeycomb. In contrast, the untreated, end-coated blanks that were dried according to the normal schedule, which is widely used commercially, came through in good condition.

Effect on Shrinkage During Kiln Drying

The data summarized in Table 1 show that soaking in polyethylene glycol solution reduced shrinkage of the treated stock blanks to from one-half to one-sixth of that of comparable untreated blanks. The variation within treatments noted in the table is due largely to the fact that some of the blanks were from quarter-sawn planks, some from flat-sawn planks, and some from planks varying somewhere between flat and quarter sawn. In all wood, shrinkage and swelling are greatest tangential to the annual growth rings (flat sawn), somewhat less radially (quarter sawn), and least of all longitudinally.

Shrinkage and Swelling of Critical Areas of Finished Stocks Can Be Virtually Eliminated

The data summarized in Table 2 show how chemically stabilized rifle stocks compare with untreated ones in shrinkage and swelling when exposed to extremes of relative humidity. In this experiment, the seasoned stocks were subjected to conditions that are more severe, in range and duration, than those likely to be encountered in normal use.

The chemically treated precarved rifle stocks and an equal number of untreated stocks shaped and inletted in the usual manner from kiln-dried blanks, were first placed in a conditioning room maintained at a constant 80° F. and 30 percent relative humidity. They were weighed weekly until they showed no significant change in weight, indicating that they had attained equilibrium moisture content for this temperature and humidity. Their dimensions were then carefully measured at several points with a micrometer, after which they were all transferred to another conditioning room maintained at a constant 80° F. and 90 percent relative humidity.

In a little over 5 weeks, the stocks had absorbed sufficient water vapor to reach equilibrium moisture content for the 90 percent humidity environment. They were again micrometered, and their expansion was expressed as a percentage of their dry dimension in the 30 percent humidity environment. These are the data summarized in Table 2. When the stocks were again placed in the low-humidity room they lost the moisture they picked up in the 90 percent humidity environment, and they shrank back to approximately their former dimensions.

The swelling that resulted from cycling the stocks between the low- and high-humidity environments was less (from 2.6 to 3.6 percent for the un-

Technologist inspects precarved stocks following chemical treatment and before kiln drying.

Technologist using micrometer to obtain precise measurement.

Precision balance was used to weigh stocks at various stages during processing.

treated stocks) than the shrinkage (Table 1) of the walnut blanks from the green to the kiln-dry condition. This is because the chemical and physical changes that take place during the drying process are such that seasoned wood can never again swell to its original green dimensions, regardless of how long it is exposed to high humidities. However, the shrinkage and swelling that occur in even such relatively stable woods as walnut, mahogany, and cherry under normal use conditions are sufficient to cause trouble for certain demanding uses, including stocks for highly accurate rifles.

As shown by the data in Table 2, the polyethylene glycol treatment greatly reduced the shrinkage and swelling that normally accompany exposure to extremes of relative humidity. Most significant is the reduction across the forearm in the area of the barrel groove and action. Shrinkage and swelling in this critical area is reduced to 1 percent—only a little over one-fourth that of untreated stocks. It can be considered as negligible for the range and duration of humidity conditions to which most rifles are exposed in normal use. This is especially true in view of the fact that most finished stocks are coated with a varnish or resin-base sealer that retards, but does not prevent, moisture movement into and out of the wood.

For the purists who wish to go all the way, shrinkage and swelling in the critical areas can be virtually eliminated by increasing the period of soak. Dr. Stamm's earlier work shows that when the amount of chemical diffused into the wood reaches 30 percent of the dry weight of the wood, normal shrinkage and swelling at the very extremes of relative humidity are reduced by more than 82 percent. Fortunately, penetration of the chemical is greatest in the vicinity of the barrel groove and action, where a high degree of dimensional stability is most important. Here the wood is relatively thin, and the chemical diffuses into it from two sides.

It has been assumed by some that bedding the barrel and action in "glass" (a commonly used generic term applied to various plastics) will keep barrel, action, and stock in perfect alignment. Although glass bedding has some desirable features, it is not the answer to this particular problem. The glass is bonded to and supported by the wood of the stock. When the stock shrinks and swells with variations in relative humidity, so does the plastic. The forces exerted by swelling wood are tremendous, and no relatively thin layer of plastic, regardless of its inherent strength, can have a significant restraining effect on normal shrinkage or swelling of the supporting wood. The chief advantages of glass bedding are that it enables an amateur to do an acceptable job of bedding, and that the plastic does significantly increase strength in critical areas around the recoil lug and rear tang.

Another common misconception i that wood will not shrink or swell appreciably after kiln drying. This, o course, is not true, as the data in Tabl 2 clearly show. An equally erroneou assumption is that the commonly use stock finishes—varnishes, resin-bas sealers, lacquers, linseed oil, etc.—pre vent the movement of water vapor int and out of the stocks with changes i relative humidity, and thus preven shrinkage and swelling. Nothing coul be further from the truth. No finis known will *prevent* the movement o water vapor into and out of wood Even the best merely slow up th process. Linseed oil and other oil-bas finishes, although they have some de sirable properties, are especially in effective in slowing up water absorption and loss.

Effect of Chemical Treatment on Strength, Gluing, Finishing, Resistance to Rot, and Weight

A comprehensive series of experiments by Dr. Stamm on matched specimens of treated and untreated wood showed that polyethylene glycol-1000 has no effect upon the toughness of wood. It reduces the modulus of rupture, modulus of elasticity, and abrasion resistance of wood only slightly, and by about the amount that would be expected from the reduction in shrinkage. The effect of the stabilizing chemical on strength is not considered to be of any practical significance.

Wood specimens treated with polyethylene glycol were successfully bonded together with a wide variety of common glues. Strength of the glued joints was determined by measuring the tensile load required to break th glued specimens. Casein, cold-setting urea, and hot-setting phenolic glues gave the highest readings for tensil strength.

None of the common gunstock fin ishes tested dried well over wood treated with polyethylene glycol, an adhesion and durability were generally poor. Only a new polyurethane resin base finish proved entirely satisfactor from all standpoints. It dried rapidly and gave a beautiful, tough, durable water-resistant finish.

Table 1.--Average shrinkage of chemically treated and untreated walnut shotgun blanks dried from the green to the kiln-dry condition according to two drying schedules

Treatment	Shrinkage, based on dry dimension			
	Normal kiln schedule		Drastic kiln schedule	
	Width	Thickness	Width	Thickness
	Percent	Percent	Percent	Percent
Polyethylene glycol-1000[1]				
Average	2.6	2.1	2.0	1.2
Range	1.7-3.3	1.7-2.7	1.1-2.6	0.4-2.3
Untreated				
Average	4.4	7.1	8.8	7.4
Range	2.1-5.9	5.8-10.9	3.8-12.9	4.2-10.3

[1] Soaked 39 days in 30 percent (by weight) solution of polyethylene glycol-1000.

Table 2.--Dimensional changes in treated and untreated rifle stocks exposed to extremes of relative humidity[1]

Treatment	Expansion, based on dry dimension		
	Butt, from heel to toe: Percent	Butt thickness, midway between heel and toe: Percent	Across forearm: Percent
Polyethylene glycol-1000[2]	1.8	2.2	1.0
Untreated[3]	2.6	3.6	3.6

[1] Cycled between two conditioning rooms maintained at constant conditions as follows: (1) 80° F., 30 percent relative humidity; (2) 80° F., 90 percent relative humidity.

[2] Green, precarved stocks soaked 24 days in 30 percent (by weight) solution of polyethylene glycol-1000, then kiln dried.

[3] Stocks shaped and inletted in usual manner from untreated kiln-dried blanks.

Treated specimens of wood were subjected to the standard ASTM soil-block culture test for 3 months after inoculation with fungi. The results of these tests show that treatment with polyethylene glycol-1000 increased the resistance of the wood to decay.

The amount of polyethlene glycol absorbed by a precarved stock during treatment does not result in an appreciable increase in the weight of the finished stock. One reason is that there is relatively little chemical in the thick part of the butt, where a high level of stability is unimportant. Moreover, the weight of the added chemical is largely offset by what amounts to a reduction in the density of the seasoned wood. Since chemical treatment restrains normal shrinkage during drying, the weight of wood substance in a stabilized stock is less, per unit of kiln-dry volume, than in an untreated stock that shrinks normally during the drying process.

Limitations of Treatment

The cost of the chemical itself is not excessive when purchased in minimum commercially available quantities of 500 pounds or more. However, the relatively long period required for chemical treatment—24 or more days for precarved stocks and 39 days for blanks—may tend to limit commercial application, especially in the processing of blanks. In this connection, it should be pointed out that research in progress shows promise of developing more efficient means of getting the chemical into the wood. Now under test are elevated temperatures in the soaking vats and a series of short-period dips in pure molten polyethylene glycol followed by conditioning in warm, moist environments. It is hoped that these techniques may speed up diffusion of the chemical into the wood fibers, and thus reduce the time required for treatment of both precarved stocks and thick blanks.

Another disadvantage, but one easily overcome, is that polyethylene glycol is readily soluble in water. Over a long period of time it would tend to leach out in substantial amounts with exposure to rain and an occasional accidental dunking in some mountain stream. Several coats of the polyurethane resin-base finish, mentioned previously, will prevent such leaching. It should, of course, be applied to the barrel groove and the inletted areas around the action and magazine box, as well as to visible parts of the stock. Although the polyurethane finish, like all others, is somewhat permeable to water, it forms a protective membrane that is practically impervious to the large molecules of polyethylene glycol-1000. Test specimens that had been treated with polyethylene glycol and then coated with the polyurethane finish lost practically none of the stabilizing agent even after complete immersion in running water for 2 weeks. Moreover, the finish showed no sign of blistering or other deterioration.

To be fully effective, the polyethylene glycol treatment must be applied to green wood fresh from the saw. It is not recommended for use on lumber or blanks that have been exposed to drying conditions for even a few days, and cetrainly not for air-dried or kiln-dried blanks or finished stocks.

Advantages

The greatest single advantage of the polyethylene glycol treatment, from the standpoint of the rifleman, is the high degree of dimensional stability attainable in critical areas of precarved stocks. Shrinkage and swelling can be reduced to a negligible amount—substantially less than the thermal expansion of most plastics.

Precarving itself has certain distinct advantages: Green wood can be shaped, sawed, and inletted more easily than seasoned wood, and does not dull cutting tools as rapidly. Moreover, the dust problem around the milling machines and duplicators is largely eliminated.

Chemical treatment of the precarved stocks practically eliminates splits, checks, and other degrade during seasoning, and permits kiln drying on an accelerated schedule that reduces drying time by about 2 weeks. Or the treated precarved stocks can be air dried over a longer period with equally good results.

Even when thoroughly seasoned, wood treated with polyethylene glycol works more easily than equally dry untreated wood. According to Ike Wynnemer, owner of the Win-A-Mer Company, "this chemically stabilized wood certainly cuts, carves, and shapes better than any wood I have worked with in my 20 years of stock making. It's a pleasure to fit a barrel and action to one of these stocks." One reason for this is that bulking the wood fibers with polyethylene glycol is somewhat comparable to the common laboratory technique of embedding plant and animal tissue in paraffin to provide support and otherwise facilitate the cutting of thin sections for microscopic examination.

It is believed that chemically stabilized stocks will out-perform any substitute material thus far developed and at the same time retain the natural warmth, beauty, durability, and other desirable properties of the fine hardwoods long prized by American sportsmen.

The polyethylene glycol treatment is also effective in preventing seasoning degrade of end-coated stock blanks. Thick walnut blanks that are end coated and then treated with the chemical can be kiln dried on an accelerated schedule without appreciable degrade, or air seasoned over a longer period with equally good results. Stocks made from the treated blanks do not have the high degree of dimensional stability found in the precarved stocks because the outside areas containing most of the chemical are cut away during machining to the finished dimensions. Here the objective is simply to get enough chemical into the thick blanks to prevent seasoning degrade and to permit faster kiln drying.

UNDERCURE . . .

Casehardening in Plywood[1]

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Undercure of hot-press phenolic resin bonds produces low wood failures. This is probably not an adequate bond although it is so classed by the industry standard of bond quality. Factors that induce undercure include: too high veneer drying temperature, too long veneer drying time or storage, high veneer moisture content, and short assembly time. Further study will be on nature of wood changes that lead to undercured bonds.

In the manufacture of softwood plywood in western Canada and the United States, low wood-failure is considered to be synonymous with low bond quality (9, 19, 25).[3] There are causes of low wood-failure other than poor bond quality, however, such as the angle at which the grain of the wood interests the glue line, wood that is stronger than the glue, and incompletely cured bonds of a type that will continue to cure in service.

The unsatisfactory conditions presented by some or all of these different tyes of low wood-failure in the past have been referred to as "casehardening" by a number of research workers and users of wood glues. Casehardening, for the purpose of this paper, will be defined as a change in the surface condition of the wood, other than a surface coating from external sources, such as oil or gum, that is induced or intensified by the manufacturing processes and that makes the surface difficult to glue. A characteristic of casehardening is that it can be corrected by lightly sanding the surface of the wood.

Research was started in 1950 to provide explanations for gluing difficulties that had baffled both plywood and glue manufacturers. The nature of the problem was that a gluing process which normally produced satisfactory bonds would, occasionally, produce an abnormally large percentage of low wood-failure bonds that would not pass the industry standard. These unsatisfactory bonds were not explainable by the usual factors such as glue mix, glue spread, pressing procedures, veneer moisture content, and so forth. In the beginning they were reported to occur during freezing weather and with interior-grown but not with coast-grown[4] Douglas-fir, but since then other situations have been found in which defects of this type tend to occur, such as in veneers dried at extremely high temperatures and in certain species of wood.

The results of the initial studies that have been reported (17) indicated that the low wood-failure was due to reduction in strength of the wood, particularly at the surface of the veneer, by drying veneers at execessively high temperatures, for excessively long times, or both. Because the validity of these conclusions was questioned by such authorities as the U.S. Forest Products Laboratory and industrial glue experts, it was decided to carry the investigation farther. The resulting evidence justified this skepticism and, at the same time, seemed to confirm the finding that the reduced strength of the wood, caused by drying at excessively severe schedules, is one of the factors that tend to produce low wood-failure in exterior-quality Douglas-fir bonds.

Influence of Dryer Temperature on The Gluability of Engelmann Spruce

The decision to continue research on the influence of veneer drying conditions upon the bond quality coincided with reports that industry was having more difficulty maintaining satisfactory exterior bond quality with Engelmann spruce than with Douglas-fir. As a consequence, this project (21) was established to study the effect of the following factors on the bond quality of Engelmann spruce:

1) the dryer temperature (and time in the dryer); 358, 378, and 393°F.
2) the time that the dry veneer was stored before it was glued; 3 and 30 days.
3) sapwood versus heartwood.

One sheet of heart and one sheet of sap veneer was collected from each of 60 Engelmann spruce logs that had been steamed for 20 hours before they were peeled. This was sufficient to provide 15 panels and 5 spare panels for each treatment combination. The moisture content of the green material ranged from 110 to 253 percent for sapwood and from 19 to 90 percent for heartwood. The veneer was dried in an 18-section, cross-circulation steamheated, roller veneer dryer. The dryer was operated at three different steam pressures, 150, 200, and 250 psi, which resulted in average temperatures in the hottest section of 358, 378, and 393°F. respectively. The corresponding drying times were 25, 16 and 13 minutes for heartwood and 40, 28½, and 25 minutes for sapwood.

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[1] A contributed paper, received July, 1959.

[2] The Forest Products Laboratories of Canada are a Division of the Forestry Branch, Department of Northern Affairs and National Resources.

[3] Numbers in parentheses refer to the Literature Cited at the end of this paper.

[4] The phrase "coast-grown Douglas-fir" is approximately synonymous with "soft-grained Douglas-fir" and "interior-grown" and "hard-grained".

To insure realistic dryer operating conditions, the experimental veneers were run while the dryer was filled with Engelmann spruce veneers with corresponding moisture contents. Twenty sheets of heart and 20 sheets of sap were dried at each temperature. Immediately after each veneer was dried, it was cut into 7 pieces, each 15 inches square. One was used for moisture determination and the other six, after they were randomized, were divided into 2 groups of 3 veneers, one group for gluing into a 3-ply panel after 3 days of storage, and the other for gluing after 30 days of storage. The entire 120 pieces of 15-inch-square veneer produced from one group were wrapped in a polythylene bag to avoid moisture cahnge during storage.

A hot-press phenolic resin glue was spread 50 pounds per thousand square feet of double glue line, given 5 minutes closed assembly time, pressed for 10 minutes at 285°F. and 200 psi (two panels to the opening), and hot stacked for 7 hours in an oven at 175°F.[5] These panels should have been over-cured because the manufacturers specified only 5 minutes of hot-pressing plus hot stacking.

Six independent estimates of bond quality were obtained for each panel, that is, the breaking load and the percentage of wood failure for each of (a) plywood shear specimens that had been subjected to the CSA 0121–57 Cold Soak Cycle (9)[6], (b) glueline-cleavage tests of untreated specimens, and (c) glueline-cleavage tests of specimens that had been subjected to an accelerated weathering treatment that consisted of soaking for 24 hours in water at approximately 70°F., followed by 14 cycles of 4 hours in boiling water and 20 hours drying at 225°F.

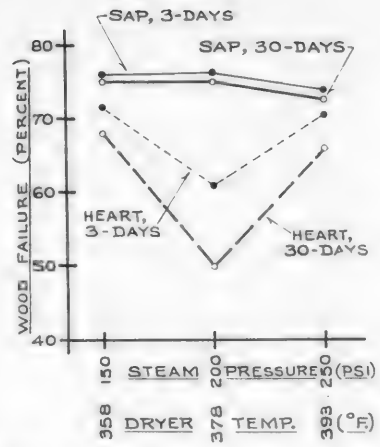
Results—General—The results of this study in terms of average breaking loads (or wood failures) of all the specimens tested from the 15 panels of each treatment combination (450 specimens per treatment combination) are set forth in Figs. A–1 and A–2.

Veneer drying temperature: In Fig. A–1 it may be seen that the veneer drying temperature had little effect upon the wood failure of the sap veneers. In Fig. A–2 it may be seen that temperature did have some effect upon the strength of these veneers; the higher the temperature the lower the strength.

In the case of heart veneers, there was no appreciable difference between those dried at the highest or at the lowest temperature, either with wood failure or with breaking load, but both the wood failures and the breaking loads were very low for the intermediate temperature. This result was quite unexpected in the light of previous work with Douglas-fir (17), which had shown that high temperatures produced inferior bonds.

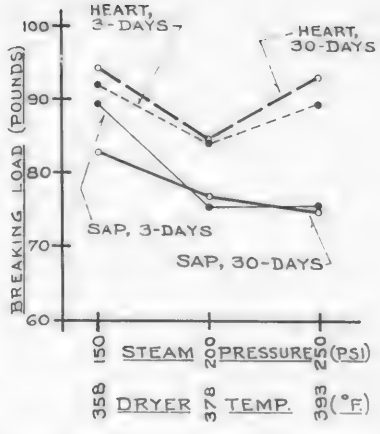
Analysis of the drying times at different temperatures suggests that the intermediate temperature schedule was the least severe of the three. This was borne out by a review of the moisture contents of the veneers, which were generally below two percent for the highest and lowest temperatures but which averaged 2.4 percent with a maximum of 10.2 percent for sap and 6.1 percent for heart for the veneers dried at intermediate temperature. In addition, one panel from the intermediate group was culled because it felt damp; thus, it appeared that the cause of the poor showing of the veneers dried at intermediate temperature was under-drying, rather than over-drying.

Veneer storage time—3 versus 30 days: Storing sap veneers for 30 days before they were glued had little effect on the bond quality, whether estimated from the wood failures or from the breaking loads. In the case of heart veneers, the wood failure was appreciably reduced by the long storage time.



NOTE:- EACH POINT IS THE AVERAGE OF 450 TESTS.

Fig. A-1.—The effect of dryer temperature, dry-veneer storage time, and sapwood or heartwood on wood failure.



NOTE:- EACH POINT IS THE AVERAGE OF 450 TESTS.

Fig. A-2.—The effect of dryer temperature, dry-veneer storage time, and sapwood and heartwood on breaking load.

A side experiment, which consisted of gluing two panels from one veneer that had failed to dry (moisture content approximately 12 percent) and 28 panels from veneers that had been dried and then re-humidified to approximately 8 percent moisture content, indicated that the rehumidification was even more detrimental to bond quality than the storage time. The two panels from the wet veneer glued reasonably well, with the breaking loads and wood failures being somewhat low when tested after the cold-soak-cycle treatment, but many of the specimens from veneers that were re-humidified to 8 percent delaminated during the cold-soak-cycle, and the average breaking load was less than half of normal. The average wood failure was reduced to 20 percent. When selected panels were re-pressed about two weeks later, there was a substantial increase in the breaking load and wood failure, although the panels were still, in general, substandard.

Sap versus heart: The sap had consistently higher wood failure and contently lower strength than heart. It is probable that the lower strength of the sap is due to the longer time it was exposed to the rather severe drying temperature of the dryer, and it is also probable that the higher percentage of wood failure of the sap is due to its lower strength, which increases the probability that failure will occur through the weakened wood.

Results—Panels with Less than 60 Per Cent Wood Failure: Table 1 lists the percentage of panels in each treatment combination in which the average wood failure of the plywood shear specimens was less than 60 percent.

[5] Throughout this paper, unless there is a specific reference to the contrary, the same hot-press phenolic resin adhesive has been used, and, unless specifically mentioned, the pressing conditions are those recommended by the glue manufacturer including the spread, press temperature, and pressure mentioned above.

[6] Canadian Standards Association CSA 0121 1957 Specification for Douglas Fir Plywood and Western Softwood Construction Plywood. . . . "The (plywood shear specimens shall be submerged in water at room temperature for a period of 48 hours and dried for 8 hours at a temperature of 145°F. (±5F and this then followed by two cycles of soaking for 16 hours and drying for 8 hours under the conditions described above. The shear specimens shall be soaked again for a period of 16 hours and tested while wet. . . . ".

On the basis of this evaluation, which approximates the industry standard, it should be noted that every treatment combination produced at least one out of fifteen panels, or seven percent, that would have failed the industry standard.

Table 1.—PERCENTAGES OF PANELS WITH AVERAGE WOOD FAILURE LESS THAN 60 PERCENT

Sap or heart	Storage time (days)	Veneer-drying temperature (Degrees Fahrenheit) 358	378	393
Sap	3	27	7	13
	30	7	13	7
Heart	3	13	40	13
	30	27	67	60

Temperature: The intermediate-temperature 30-day heart made the poorest showing, 2/3 of the panels failed. The high-temperature 30-day heart was a close second, and the intermediate-temperature 3-day heart the third poorest. This analysis confirms the previous one but, in addition, shows that the highest temperature, in combination with the longer storage time, resulted in poor bonds.

30 versus 3 days storage: This analysis confirms the former one that storage time had little effect upon the sap, but that the longer storage was detrimental to the heart.

Sap versus heart: The indication is that the heart is seriously affected; the sap very little.

Results—Re-analysis of Wood Failures: To learn more about the behavior (bond quality) of the low woodfailure panels, the data were reanalyzed, and these analyses are summarized in Figs. B–1 and B–2. The panels were divided into two groups on the basis of their wood failure as recorded for the untreated specimens that were tested by the glueline-cleavage method, one group with average wood failures from zero to 69 percent, and the second group from 70 to 100 percent. The average breaking load and the average wood failure were then calculated for each group, both for the untreated specimens and for the specimens that had been subjected to the rather severe accelerated weathering treatment prior to test.

The average breaking load of the 0 to 69 percent wood-failure group was 11 percent higher than that of the 70 to 100 percent wood-failure group in the case of the untreated specimens (Fig. B–1), and this superiority in strength increased to 19 percent after the accelerated weathering treatment. This seems to indicate that, in this instance, low wood-failure is not an indication of an inadequate bond.

From Fig B–2 it may be seen that, in the case of the 70 to 100 percent group, the wood failure decreased

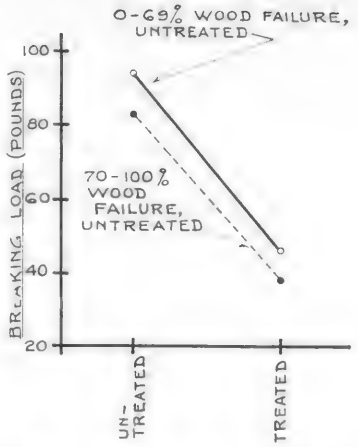


Fig. B-1.—The effect of initially low or initially high wood failure and accelerated weathering treatment on breaking load.

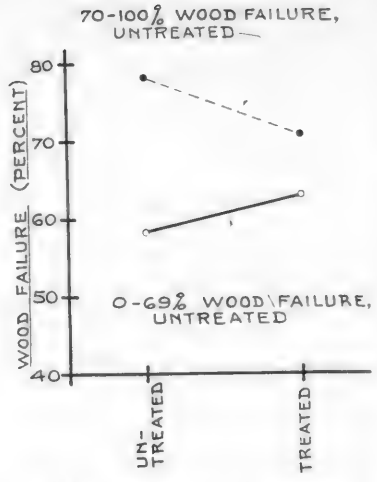


Fig. B-2.—The change of wood failure induced by accelerated weathering treatmen in initially low and initially high wood failure panels.

from 78 to 71 percent with the accelerated weathering treatment, while in the case of the 0 to 69 percent group the wood failure increased from 58 to 63 percent. This seems to indicate that, in this instance also, low wood-failure is not an indication of an inadequate bond.

In retrospect it seems plain that the low wood-failure was due to undercure of the bonds, which were sufficiently cured to withstand the delaminating effects of prolonged soaking in water but which were insufficiently cured to produce the required percentage of wood-failure. It also seems plain that the cure was continued by the boiling and drying of the accelerated weathering treatment.

Results—Cycling to Delaminated Method: The opinion that, in this case, low wood-failure is not an indication of inadequate bonding was further substantiated when representative panels of the 0 to 69 percent group and of the 70 to 100 percent group withstood 220 cycles[7] in the delamination machine (18), while specimens from the veneers that were reconditioned to 8 percent moisture content before they were glued delaminated completely in from 70 to 80 cycles.

While, in retrospect, most of the anomalies in the data are explainable, at the time the work was analyzed it seemed that there was quite inadequate understanding of and control o the variables involved. What wa needed more than anything else, befor a beginning could be made to stud the factors that were operating to pro duce "casehardening" from a funda mental (chemical, physical, mechanical) point of view, was to learn how to produce the defect at will. The studies to be reported hereinafter were all conducted with this objective.

[7] The estimate of bond quality, for the purpose of this report, is the number of cycles which produced 50 percent delamination. This, in general, is the number of cycles to delamine one of the two glue lines in a three-ply specimen. In this work, and whenever the cycling-to-delamination method is mentioned in this paper, the first cycle consists of 48 hours soaking in water at room temperature followed by drying for 8 hours at 145°F., the second and third cycles consist of soaking in water at room temperature for 16 hours followed by drying at 145°F. for 8 hours and re-soaking in water for 16 hours. Subsequent cycles consist of 10 minutes in boiling water followed immediately by immersion in ice cold water for 3.75 minutes and followed by drying for one hour in an oven at 300°F.

Bonding Interference by Adsorbed-Moisture Theory, Douglas-Fir

Out of the side experiment in which "wet" Engelmann spruce veneers glued reasonably well while veneer re-humidified to 8 percent failed to bond, grew a theory that adsorbed moisture interfered with adhesion in some way that the initially present water did not, possibly by occupying the "valences" which would normally be occupied by the glue.

To test this theory of bond interference of adsorbed moisture and since no green Engelmann spruce veneer was available, 1/8-inch Douglas-fir sapwood veneer was partially dried by putting it through the heartwood cycle in a commercial, roller-type, veneer dryer. Factory-dried sapwood veneers were also collected. Half of the partially dried veneers, with moisture content in excess of 12 percent, were dried to zero moisture content. Half of each of these groups of veneers was next conditioned in an atmosphere of 1 percent relative humidity and the remainder in a 6 percent atmosphere The actual moisture contents obtained and the bond quality as evaluated by means of the (British) knife test (6) are recorded in Table 2. Some factory-dried veneers were also rehumidified in the same atmospheres.

The actual moisture contents were 12.7 and 7.4 percent for the desorption cycle, 11.0 and 4.6 percent for the adsorption cycle, and 11.6 and 6.6 percent for the re-humidified factory-dried veneers.

After a 5minute press plus hot stack, all but the 4.6 percent adsorption panels failed. After a 10-minute press plus hot stack, only the 11.0 percent adsorption panel failed. The failure of this panel was interpreted as lending weight to the bonding-interference-of-adsorbed-moisture theory, but not to the extent anticipated.

Bonding Interference by Adsorbed-Moisture Theory, Englemann Spruce

This study was conducted to re-test the bonding-inteference-of adsorbed-moisture theory with Engelmann spruce.

The factors incorporated in the study were:

1) Veneer moisture contents of 12, 9, 6, 3 and 0 percent.
2) Desorption and adsorption cycles.
3) Closed assembly times of 0, 10, 30 and 120 minutes.

The 1/10 inch Engelmann spruce heartwood veneers were dried in an experimental kiln at the laboratory at a temperature of 300°F. They were humidified in the same kiln at 180°F. in approximately 24 hours.

The results are summarized in Table 3. Bond quality was again evaluated with the (British) knife test (6). The nominal and actual veneer moisture contents are listed at the top of each column.

With zero closed assembly time, all of the 12 percent moisture content panels failed, as did ½ of the 9 percent, ¼ of the 6 percent, and ¼ of the 3 percent. With 10 minutes assembly all of the 12 percent panels failed, and ¾ of the 9 percent. With 30 minutes assembly, ¾ of the 12 percent panels failed, and ½ of the 9 percent, and with 120 minutes assembly only one panel failed the 12 percent adsorption.

Adsorption versus Desorption: When the panels with veneers conditioned in the same atmosphere are compared, the two 12 percents, the two 9 percents, and so on, there is no evidence to justify the theory of bonding interference of adsorbed moisture. When desorption and adsorption panels with similar moisture contents are compared, however, such as 10.9 percent adsorption which produced 5/8 failures with 10.7 percent desorption which produced only ⅜ failures, or the 8.9 percent adsorption which produced ½ failures compared to the 8.7 percent desorption which produced no failures, it appears that there is some truth to the bonding-interference theory. The fundamental nature of this interference remains to be investigated.

Undercure Theory: Contemplation of the pattern of results, notably 1) failure in the region of high veneer moisture content and short assembly time, 2) good to excellent bonds in the region of low veneer moisture content; and long assembly time, (3) and poor to fair bonds at the junction of these two regions, leads to the theory that the low wood-failure or "casehardened" type of bond, which after experimentation had been reproduced at will, was due to undercured glue bonds.

The first step towards testing this theory was to subject specimens from the panels to the cycling-to-delamination process[7] (18) in the delamination machine. The results are listed in Table 4. A larger number indicates better bond quality.

Table 2.—KNIFE-TEST ESTIMATES OF BOND QUALITY FOR DOUGLAS-FIR PLYWOOD

	Moisture content of veneers prior to gluing					
	12 percent			6 percent		
Press time (min.)	12.7 percent Desorption	11.0 percent Adsorption	11.6 percent Adsorption after factory dry	7.4 percent Desorption	4.6 percent Adsorption	6.6 percent Adsorption after factory dry
5	Fail Fail	Fail Fail	Fail Fail	Fail Fail	P E	Fail Fail
7½			P P			G E
10	P	Fail	P G	P	P	E E

[1] E—Excellent, G—Good, F—Fair, P—Pass.

When the two methods of estimating bond quality are compared, the cycling-to-delamination method (Table 4) with the knife test (Table 3), it is note-worthy that most of the bonds that were classed as poor to fair by the knife test due to low wood-failure withstood the cycling-to-delamination test about as well as the good to excellent bonds. It was reasoned, therefore, that the cure of the partially cured bond (poor to fair) had been continued by the heat of the boiling and drying processes so that, after a number of these cycles, the bonds were fully cured.

Undercure—Casehardening Theory, Engelmann Spruce

The objectives of this study were, first, to investigate the theory that "casehardening", or the low wood-failure type of bond that was being studied, was attributable to partially-cured bonds, and second, to study the effect of each of the following factors on the degree of cure of the bond:

a) veneer drying history (dried and redried),

Table 3.—KNIFE-TEST ESTIMATES OF BOND QUALITY FOR ENGELMANN SPRUCE PLYWOOD

	Moisture content of veneers prior to gluing								
	12 percent		9 percent		6 percent		3 percent		0 percent
Closed Assembly time (min.)	14.0 percent Desorption	10.9 percent Adsorp. tion	10.7 percent Desorption	8.9 percent Adsorption	8.5 percent Desorption	6.0 percent Adsorption	4.6 percent Desorption	4.2 percent Adsorption	2.5 percent Desorption
0	Delam Fail	Delam Fail	P P	Fail Fail	P P	F Fail	Fail F	F G	F F
10	Fail Delam	Fail Fail	Fail Fail	Fail P	F F	G G	G G	G G	F P
30	Delam Fail	Fail P	P Fail	Delam P	F P	G G	G F	E E	E E
120	P P	F Fail	F G	G E	E E	E G	E E	E E	E F

Table 4.—CYCLES TO CAUSE 50 PERCENT DELAMINATION—ENGELMANN SPRUCE

	Moisture content of veneers prior to gluing								
	12 percent		9 percent		6 percent		3 percent		0 percent
Closed assembly time (min.)	14.0 percent Desorption	10.9 percent Adsorption	10.7 percent Desorption	8.9 percent Adsorption	8.5 percent Desorption	6.0 percent Adsorption	4.6 percent Desorption	4.2 percent Adsorption	2.5 percent Desorption
0	0 0	0 0	98 128	143 122	130 154	200+ 200+	120 200+	200+ 200+	200+ 175
10	90 85	52 45	175 87	200 140	200+ 200+	200+ 200+	200+ 200+	200+ 200+	200+ 200+
30	89 100	116 128	175 195	124 200+	200 122	200+ 200+	200+ 200+	200+ 200+	200+ 200+
120	152 200	200+ 200+	200+ 200+	200+ 200+	200+ 200+	200+ 200+	200+ 200+	200+ 200+	200 130

Table 5.—KNIFE TEST ESTIMATES OF BOND QUALITY—ENGELMANN SPRUCE

Closed assembly time (min.)	Veneers unsanded or sanded prior to gluing	Dried						Re-dried					
		Percent moisture content						Percent moisture content					
		3 percent		6 percent		9 percent		3 percent		6 percent		9 percent	
		Press time (minutes)		Press time (minutes)		Press time (minutes)		Press time (minutes)		Press time (minutes)		Press time (minutes)	
		5	10	5	10	5	10	5	10	5	10	5	10
1	Unsanded	Fair Fair	Poor Fair	Fair Poor Poor Delam	Poor Poor Fair Poor	Delam Delam Delam Delam	Delam Delam Delam Delam	Delam Delam	Poor Poor	Delam Delam Fair Delam	Poor Delam Poor Delam	Delam Delam Delam Delam	Delam Delam Delam Delam
120	Unsanded	Fair Fair	Good Fair+	Fair Fair Fair— Fair	Fair+ Fair— Fair Fair	Fair Poor— Fair Poor	Poor Poor Poor Poor	Fair— Fair—	Fair Good—	Fair Poor Poor Poor	Fair Fair Fair Fair	Delam Delam Poor Delam	Delam Poor Poor Fair—
1	Sanded before gluing	Fair Good		Good Fair+ Fair Fair—		Fair Fair Fair Fair		Fair Fair+		Good Good Good Good		Poor Poor Poor Fair—	

b) veneer moisture content (3, 6, and 9 percent),
c) closed assembly time (1 and 120 minutes),
d) press time (5 and 10 minutes).

Engelmann spruce heart veneers, 1/10 inch thick were used. Half of the veneers were dried for 16 minutes in a commercial roller-type veneer dryer with maximum temperatures of approximately 370°F., and the other half were severely "redried" by passing them twice more through the dryer.

Because the moisture content of the veneers seemed to be very important and quite critical, it was decided to measure the moisture content of each veneer immediately before it was glued. No moisture meter was available that would accurately measure the moisture in the range of 0 to 6 percent, so this was accomplished by drying all of the veneers to zero moisture content (24 hours at 225°F.), weighing each oven-dried veneer, rehumidifying the veneers to the dried moisture content, storing those of the same nominal moisture content in waterproof bags, and re-weighing each veneer just before it was glued.

Some spare veneers were sanded just before they were glued when it became clear that the average bond quality was rather low, probably because of the excessive amount of heat to which the veneers had been subjected (24 hours at 225°F. to oven-dry and 24 hours at 180°F. to re-humidity). The knife-test data are presented in Table 5 and summarized in Table 6.

The conclusions were as follows:

1) With one exception, the only good panels were from sanded veneers.
2) Drying reduced the gluability of of the wood.
3) Redrying reduced the gluability even more.
4) Sanding restored gluability, therefore the defect under study is a surface phenomenon.
5) Pressing for 10 minutes produced better bonds than pressing for 5 minutes, therefore undercure seems to enter into the problem.
6) The 120-minute assembly time was better than the 1-minute, therefore concentration of water at the veneer surface seems to be a factor.
7) Veneer at 3 percent moisture content produced higher bond quality than veneer at 6 percent, and 6 percent was better than 9 percent for unsanded veneers. Sanded veneers at 3 percent and 6 percent produced equal bond quality and both were superior to 9 percent. This seems to indicate that the degree of undercure varies directly with the moisture content, and that it is a surface condition.
8) The inner glue line is more critical than the outer.

In summary, it was concluded that the veneer dryer created a surface condition on the veneer that was intensified by over-drying, and that reduced the gluability of the veneer in at least two ways:

1) reduced the wood failure independently of the cure of the adhesive and,
2) tended to produce undercured bonds. The degree of undercure varied directly with the moisture content, directly with the time in the dryer, inversely with the assembly time, and is a surface phenomenon that can be corrected by sanding. It is considered that the factor that reduces the wood failure independently of the cure of the adhesive is the reduction in strength of the wood due to the excessively severe veneer-drying schedule (17).

Undercure-Casehardening. Several Species and Glues

To provide a wider background against which to evaluate theories on the fundamental (physical, chemical, mechanical) causes of "caseharden ing", and to further check the under cured-bond theory, an experiment wit a wider range of species of wood an glues was undertaken.

The species were chosen to includ a wide range of characteristics includ ing softwood and hardwood, resinou and non-resinous, hard and soft grain and a range of densities. The specie chosen were black cottonwood (*Pop ulus trichocarpa* Ton. and Gray) Douglas-fir (*Pseudotsuga menzies* (Mirb.) Franco) (both coast-grown and interior-grown), Engelmann spruce (*Picea Engelmann Parry*), and one of the western Abies (probably *Abies amabilis*).

One glue was the same phenolic resin that was used for the other work reported. With this glue there was complete replication of the other factors. The other glues, a cold-press casein and a hot-press urea, were used only with veneers at 6 percent moisture content.

In addition to species and glues, the factors incorporated in the study were:

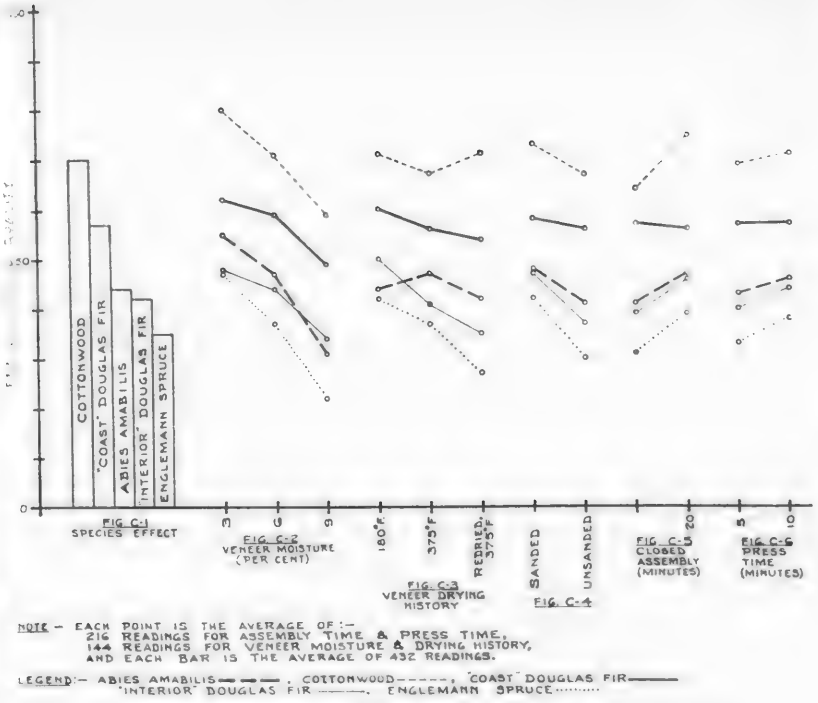
1) Veneer drying history; dried at 180°F., 375°., and re-dried at 375°F.
2) Veneer moisture contents: 3, 6, and 9 percent.
3) Closed assembly time: 1 and 20 minutes.
4) Press time: 5 and 10 minutes.
5) Sanded and unsanded veneers.

Only one 12-inch-square panel was made for each treatment combination This gave a total of 496 panels.

The veneers dried at 180°F. were dried in a laboratory kiln, while th 375°F. veneers were dried, or re-dried in a commercial roller-type dryer with maximum temperature of approxi mately 375°F. as recorded by the side indicating thermometers.

Pressing conditions for all panel followed the manufacturers' recom mendations for Douglasfir.

The bond quality was estimated by the same two methods that were used in the other studies, the (British)


COTTONWOOD
"COAST" DOUGLAS FIR
ABIES AMABILIS
"INTERIOR" DOUGLAS FIR
ENGLEMANN SPRUCE
FIG. C-1 SPECIES EFFECT
FIG. C-2 VENEER MOISTURE (PER CENT)
180°F
375°F
REDRIED
FIG. C-3 VENEER DRYING HISTORY
SANDED
UNSANDED
FIG. C-4
FIG. C-5 CLOSED ASSEMBLY (MINUTES)
FIG. C-6 PRESS TIME (MINUTES)
NOTE – EACH POINT IS THE AVERAGE OF:– 216 READINGS FOR ASSEMBLY TIME & PRESS TIME, 144 READINGS FOR VENEER MOISTURE & DRYING HISTORY, AND EACH BAR IS THE AVERAGE OF 432 READINGS.
LEGEND:– ABIES AMABILIS – – –, COTTONWOOD – – – –, "COAST" DOUGLAS FIR ——— "INTERIOR" DOUGLAS FIR ———, ENGLEMANN SPRUCE .....

Figs. C-1 to C-6.—Influences of different factors on the bond quality of phenolic-bonded plywood.

knife test and the cycling-to-delamination method[7] (18). With the knife test, specimens were tested after each of the following four different treatments:

1) immediately after removal from the hot press,
2) after an 18-hour hot stack in an oven at 200°F., and subsequent cooling,
3) after the hot-stack treatment plus the cold-soak cycle,[6]
4) after the hot-stack treatment plus 72 hours in boiling water.

When wood failure is mentioned, it is the average read from the three knifings after the hotstack treatment for the poorer of the two glue lines. Three specimens from each panel were subjected to the cycling-to-delamination test, and each figure quoted is the average of the three.

In general in this study, the two methods (wood failure and cycling-to-delamination) told the same story, so they have been combined into a single estimate of bond quality called percent bond quality[8] for the purpose of this report.

Results—General: A general inspection of the results showed that:

1) as expected, the relative durability of the urea and casein glues was much poorer than that of the phenol glue, when all plywood was manufactured under optimum conditions,
2) the casein performed better than the urea,
3) the three glues performed differently when used with different species. With urea and casein, cottonwood performed very well, and Abies did much better than did Engelmann spruce or Douglas-fir.
4) sanding improved the bond in some cases and not in others. Sanding greatly improved the bond with both casein and urea, when used with Engelmann spruce and Douglas-fir, and made some improvement with urea when used with Abies and cottonwood, but it made no improvement when casein was used with Abies and cottonwood.

Results—Phenolic Bond Averages: The main body of information, which is for hot-press phenolic-resin plywood, and which will be discussed in more detail, is presented graphically in Figs. C, D, E. F and G.

Figs. C1 to C6 present the data with all factors averaged except the one being presented. For example, in Fig. C1, which compares the species effect, the factors averaged are moisture content, drying history, sanded versus unsanded, assembly time and press time; each bar is the average of 432 readings on 72 panels. In Fig. C2, each point is the average of 144 readings on 24 panels, with the following factors

[8] For the purpose of this report, percent bond quality will be abbreviated to percent BQ.

Table 6.—SUMMARY OF KNIFE TEST ESTIMATES OF BOND QUALITY—ENGELMANN SPRUCE

Closed assembly time (min.)	Sanded	Dried						Redried						Totals					
		Percent moisture content						Percent moisture content						Percent moisture content					
		3 percent		6 percent		9 percent		3 percent		6 percent		9 percent		3 percent		6 percent		9 percent	
		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)		Press time (min.)	
		5	10	5	10	5	10	5	10	5	10	5	10	5	10	5	10	5	10
1	Unsanded	Fair	Fair	Poor—	Poor+	Delam	Delam	Delam	Poor	Delam+	Delam+	Delam	Delam+	Poor	Fair—	Delam+	Poor	Delam	Delam+
120	Unsanded	Fair	Good	Fair	Fair	Fair—	Poor	Fair—	Fair	Poor	Fair	Delam+	Poor	Fair—	Fair	Fair—	Fair	Poor	Fair—
1	Sanded	Good—	Fair+	Poor	Fair—	Delam+	Delam+	Fair+	Poor—	Delam+	Poor	Delam	Delam+	Fair—	Fair	Poor	Poor+	Delam+	Poor
120	Sanded	Fair+	Fair	Poor+	Fair	Delam+	Delam+	Poor	Poor+	Delam+	Poor	Delam	Delam+	Fair+	Good—	Poor	Fair	Delam+	Poor+

averaged: drying history, sanded versus unsanded, assembly time, and press time.

Species effect: Fig. C1 presents the average percent BQ for each of the species included in the study. The values ranged from 70 for cottonwood to 35 for Engelmann spruce, and indicated a large species effect. The difference between coastgrown and interiorgrown Douglas-fir indicates a substantial genetic or physiological factor.

Veener moisture effect: From Fig. C2 it may be seen that the bond quality of all species decreased with increasing moisture content.

Drying history effect: Reference to Fig. C3 will show that different species appear to have reacted differently to the veneer-drying process; Douglas-fir and Engelmann spruce were adversely affected by increasingly severe drying schedules, but cottonwood and Abies were unaffected.

Sanding effect: The data of Fig. C4 indicate that sanding improved the and quality of plywood of all species, but coast-grown Douglas-fir was improved the least.

Closed assembly time: The data of Fig. C5 indicate that the longer assembly time improved the bond in all species except coast-grown Douglas-fir.

Pressing time effect: The longer pressing time improved the bond quality of all species except coast-grown Douglas-fir, as can be seen from Fig. C6.

This is an appropriate place to draw attention to the fact that coast-grown (soft-grained) Douglas-fir has been particularly tolerant to the factors of sanding, assembly time, and press time, and to suggest that this may be because the hot-press phenolic adhesive has, in effect, been specially designed for this species at the cost of many years of research and production effort. It is suggested that a comparable research effort would produce glues that would be equally satisfactory for each of the other species.

Results—Comparison of Better Gluing Conditions: The trends that have been outlined are the averages for panels, both good and bad. It is instructive to compare the results obtained under the better gluing conditions with those obtained under the poorer gluing conditions. Fig. D presents the effects of poorer gluing conditions (1-minute assembly, 5-minute press, unsanded veneers) and better gluing conditions (20-minute assembly, 10-minute press, sanded veneers) on species gluability. Fig. E presents the interrelationship between poorer versus better gluing conditions and veneer moisture content on the bond quality of different species. Fig. F presents the interrelationship between poorer versus better gluing conditions and veneer drying history on bond quality of different species.

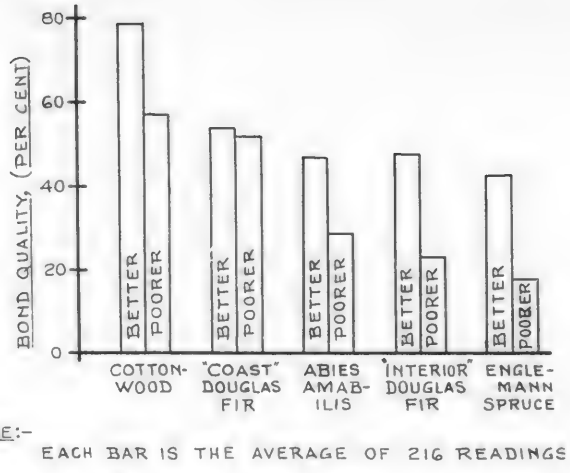


Fig. D.—The effect of poorer gluing conditions (1-minute assembly, 5-minutes press, unsanded veneers) and better gluing conditions (20-minutes assembly, 10-minutes press, sanded veneers) on species gluability.

Species effect: From Fig. D, which averages the effects of moisture content and drying history, it is clear that, for each species with the exception of Coast Douglas-fir, the poorer gluing conditions produced much lower percent BQ than did the better gluing conditions. In the case of Coast Douglas-fir there was no appreciable difference, and in the case of cottonwood the percent BQ under the poorer conditions remained higher than for any of the other species under the better gluing conditions. In the cases of Engelmann spruce, Abies, and interior-grown Douglas-fir, which were marginal under the better conditions, the degrading effect upon percent BQ was very serious. For example, in the case of Engelmann spruce, percent BQ fell from 43 to 18.

Veneer moisture content effect: From Fig. E, which averages drying history, it is noteworthy that veneer moisture content had very much greater effects upon the percent BQ of panels that were glued under the poorer conditions than upon the percent BQ of panels that were glued under the better conditions. These differences are particularly noticeable in the moisture content range of 3 to 6 percent, which is usually considered to be the optimum veneer moisture range for hot-press phenolic resin adhesives for softwood plywood. With the better gluing conditions there is no appreciable difference in percent BQ in this range while with the poorer gluing conditions there is a very severe drop in percent BQ for all species as the veneer moisture increases from 3 to 6 percent.

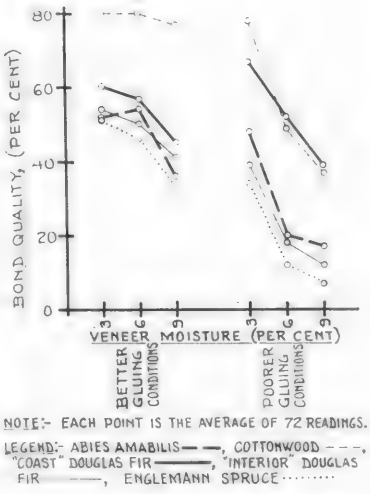


Fig. E.—The interrelationship between poorer versus better gluing conditions (1-minute assembly, 5-minutes press, unsanded veneers vs. 20-minutes assembly, 10-minutes press, sanded veneers) and veneer moisture content on bond quality of different species.

Drying history effect: Fig. F presents the drying history effects as these are influenced by better or poorer gluing conditions created by other factors. For the better gluing conditions the drying history seems to have no appreciable effect, except in the case of Engelmann spruce. With the poorer gluing conditions, the indication is that drying history is very important in the cases of Douglas-fir and Engelmann spruce. Abies and cottonwood, the two non-resinous and low-specific-gravity woods, seem to be much less sensitive to temperature.

To study the effect of various combinations of bond-degrading factors upon percent BQ, the data for Engelmann spruce were reorganized in Fig G. The top line is the average effect of veneer moisture content on percent BQ, with all factors averaged except

pecies and moisture content. Removal of the 20-minute-assembly-time data introduces, in effect, one bond-quality-degrading factor, short assembly time, into the analysis, The result is a lowering of percent BQ as indicated by the second line from the top. By continuing this process by adding two degrading factors, short assembly time and short press time, a further reduction in percent BQ is noted, as represented by the third line from the top. With three degrading factors, short assembly and press times, and unsanded veneers, the fourth line from the top is obtained. With four degrading factors, the three already mentioned plus adverse drying history (re-dried veneers), the degradation of percent BQ has reached its maximum for this experiment and is represented by the bottom line of Fig. G. With some exceptions, which are probably due to the lack of replication, the same is true of each of the four species. Unsanded Engelmann spruce and interior-grown Douglas-fir with adverse drying history, assembly time, and present time, failed to bond for practical purposes at 9 to 6 percent moisture contents, and produced inferior bonds even at 3 percent. Under the same conditions, cottonwood, coast-grown Douglas-fir, and Abies, while adversely affected, still produced reasonable bonds.

Other Research Findings: In addition to the research already presented, several additional pieces of evidence are at hand that tend to support the undercure-case-hardening theory of low wood-failure bonds.

The first is that exterior-grade Douglas-fir plywood, which was placed on a test fence in September, 1954, and which lost considerable strength during the winter months from September, 1954 to May, 1955, then continued to increase in strength until May, 1957. The only explanation that comes to mind for this continuing increase in strength is continuing cure of the bond.

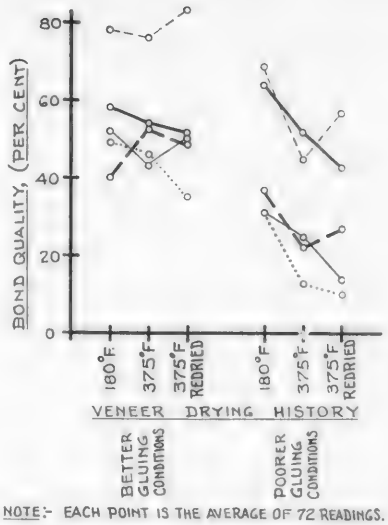
The second is that phenolic-bonded Douglas-fir plywood that failed after 24 cycles in the delamination machine when tested within a few weeks of manufacture exceeded 200 cycles when tested within a few weeks of manufacture exceeded 200 cycles when retested after one year of storage in the plywood laboratory. The same explanation seems to apply.

The third is that provided by a comparison of the severity of the British standard (6) and the Canadian standard (9) of exterior plywood bond quality. Only 3.3 percent of a sample of 60 pieces of commercial Douglas-fir plywood failed to pass the British standard (6), which required that the plywood specimens be subjected to 72 hours in boiling water before they are tested, while 16.6 percent of the sample failed to pass the cold-soaking cycle of the Canadian standard (9). This seems to indicate that, at least in this sample, the bond was not completely cured when received from the manufacturer for testing, and that the cure was continued during the 72 hours in boiling water. None of the panels delaminated.

In each of these three cases, it seems that the bond was not fully cured during the manufacturing process and that the bond continued to cure in service or storage or when further heat was received.

A fourth piece of evidence in support of the undercure-casehardening theory has been provided by microscopic examination of bonds that were expected to be fully cured and undercured. In the case of bonds that were adequately cured when removed from the hot press, the walls of the lathe checks tended to be re-glued where glue had penetrated the lathe checks, while in the case of undercured bonds the glue had failed to re-bond the lathe checks. This evidence is considered to be of diagnostic value in determining minimum permissible press times or when undercure is suspected in a hot-press plywood gluing operation.

A fifth piece of pertient information is from an unpublished study of the effect of veneer drying temperature and times upon the wetability of wood. The indication, which was similar to that observed by Stensrud (23) with cellophane and glass, was that wetability was reduced as drying temperature was increased. At the time the work was done, not much reliance was placed in the significance of this information because of the large variability between specimens. This seemed to be justified by the fact that the depth of penetration of glue was similar for specimens dried 225°F. and at 450°F. In retrospect, two major reasons can be suggested for re-appraising this information. The first reason is that the depth of penetration is likely more a function of the condition of the glue at the time of pressing and of the pressing conditions than of the wetability of the wood. The second reason is that all of these bonds were manufactured under optimum gluing conditions (with the exception of the factors under study, in this case veneer drying conditions) and it is now known that this tends to mask defects that would become critical under more marginal conditions of the other gluing factors, (that is, those not under study, such as the press temperature, pressing time, hot stack, veneer moisture content, assembly time, glue spread, and so forth.).



NOTE:- EACH POINT IS THE AVERAGE OF 72 READINGS.

LEGEND:- ABIES AMABILIS — —, COTTONWOOD – – –, "COAST" DOUGLAS FIR ———, "INTERIOR" DOUGLAS FIR ———, ENGLEMANN SPRUCE ·····

Fig. F. — The interrelationship between poorer versus better gluing conditions (as in Fig. E) and veneer drying history on bond quality of different species.

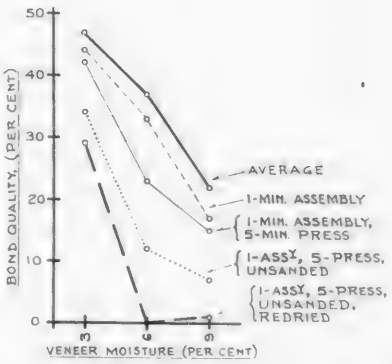


Fig. G.—The adverse effect on bond quality induced by an increasing number of adverse factors (short assembly time, short press time, over-dried veneer, unsanded veneers).

A sixth piece of information, from the same unpublished study just mentioned which may have some bearing upon this problem, is that the staining reactions of microscope specimens are different for wood dried at 450°F. than for wood dried at 375°F. Certain other differences have been observed under the microscope. One of these is an accumulation of liquid deposits that have plugged the lumen of certain cells of wood dried at 450°F. Another is an accumulation of crystalline material on the walls of certain cells of wood dried at 450°F. Neither the liquid nor the crystalline deposits were observable in wood dried at 375°F. It appeared that these were products of incipient pyrolysis that have condensed upon the cell walls.

Still another piece of information relates to the different intensity with

which drying temperature affects the strength of springwood glued to springwood and summerwood glued to summerwood. The Glueline-Cleavage breaking loads for specimens dried at temperatures of 225°, 338°, and 450° F. respectively are as follows: for springwood glued to springwood 188, 154, and 111, and summerwood glued to summerwood 245, 238, and 57. The corresponding wood failures were 100, 80, 60, and 95, 90, and 10 percent. It appears that summerwood is much more severely affected by high drying temperatures than is springwood. This appears to agree with factory information that faulty bonds were associated more with summerwood than springwood.

Undercure-Casehardening Theory of the Development of Low Wood-Failure Plywood Bonds

The first point of this theory is that the hygroscopicity or wetability of wood is reduced by certain seasoning processes or conditions, such as drying veneers at excessively high temperatures, or for excessively long times at lower temperatures, or storing the dried veneers for weeks or months at normal plant temperatures. There appear to be two probable ways in which this reduction in the hygroscopicity of the veneer may happen: firstly, by chemical changes in the wood or extractable materials, and secondly, by a lignin or resin-like substance flowing over the broken cell walls.

The second point of the theory is that, due to this reduction in hygroscopicity of the wood, or more specifically the surface of the wood, any factor that tends to increase the moisture content of the glue line tends to retain all of the glue on the surface of the veneer, and further-more to keep the glue in an abnormally fluid condition up to the time when pressure and heat are applied. The factors that tend to increase the moisture content of the glue line include high moisture content of the veneer, high moisture content of the glue, (low glue viscosity), heavy glue spread, short assembly time, and factory conditions such as high relative humidity and low temperature, which restrict the evaporation of water from the assembly.

The third point of the theory is that this abnormally fluid glue, which has been retained intact on the surface of the veneer, is made even more fluid by the sudden application of heat and penetrates abnormally deeply into the wood under the combined influence of platen pressure, steam pressure, and capillary action. This explains the occurence of migrated glue lines under these conditions.

The forth point of the theory is that glue with an abnormally high moisture content requires a longer than normal pressing time, at the same press temperature and pressure, to produce the normally required degree of cure of the adhesive. When panels with such lines are given the standard time in the hot press, the resulting bond is abnormally undecured and this is reflected in low wood-failure when the bonds are broken.

The last point of the theory is the cumulative effect of a number of adverse factors in inducing undercured bonds. With a slightly adverse level of one potentially adverse factor, such as a slightly high veneer moisture content, and optimum levels of other factors, such as glue spread and layup time, a satisfactory bond will result; with the same slightly adverse veneer moisture content in combination with slightly adverse levels of other factors, however, undercured bond will result. Stated another way, an accumulation of adverse factors is to be avoided. Adverse factors, in the case of undercured bonds, would include factors that tend to require longer press time for a given degree of cure independently of the glue moisture content, such as high-density veneer, high veneer moisture content, cold veneer, subnormal press temperature, subnormal press pressure, and so forth.

It is only fair to mention the evidence that partially cured phenolic bonds that emerge from the hot press without steam blows may be expected to complete their cure in storage or service.

Summary

This work was undertaken to explain why gluing processes that normally produced satiscfactory bonds occasionally produced abnormally large percentages of low wood-failure bonds that would not pass the industry standard of bond quality.

The work reported herewith includes bond-quality studies involving the following factors: species, glues, sapwood and heartwood, veneer drying history, dry-veneer storage time, veneer moisture content, adsorption and desorption cycles, sanded and unsanded veneers, assembly time, and press time.

The most important information provided by this research is, perhaps, the evidence that undercured bonds are a major cause of low wood-failure in softwood plywood. Also important is the evidence that unexpected factors such as the veneer-drying history, assembly time, veneer-storage time, and adsorbed moisture contribute to the severity of undercure.

It is suggested that some factors that reduce wood failure independently of the cure of the adhesive are the angle at which the cells of the wood intersect the glue line and weak cells at the surface of the veneers. A major cause of such weakened cells is incipient pyrolysis caused by drying veneers at excessively high temperatures, for excessively long times, or both.

This work has suggested, however, that low wood-failures which are due to undercured (phenolic) adhesives are not necessarily poor-quality bonds. Rather, it suggests that this particular type of bond may be expected to continue to cure in service, and that the wood-failure method of estimating bond quality may not appraise the quality of this type of low wood-failure bond with sufficient accuracy. More research is needed to clarify this picture.

It has been shown that, for a particular glue, certain species are much more sensitive than others to the factors that tend to produce undercured bonds. Differences in the tendency for different glues to produce casehardening were also demonstrated.

It is suggested that the particularly good tolerance of coast-type Douglas-fir to conditions that tend to produce undercured phenolic bonds may not be a species characteristic but may be a characteristic that has been built into that particular glue through years of research to develop the best glue for exterior quality plywood which has, in fact, been Douglas-fir plywood. It may well be that an equivalent research effort will produce glues that will work equally well with each of the other species.

The adverse effect of an accumulation of detrimental factors was demonstrated.

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RELATION BETWEEN PHYSICAL AND CHEMICAL

Properties of Wood and Adhesion[1]

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Wettability, pH, and specific gravity are closely related to glue-bond quality. Specific gravity is generally more important, and pH and wettability less, with resorcinol-phenol bonds than with urea bonds. In most respects, shear ratio, shear strength, and percentage of wood failure agree as indicators of glue-bond quality.

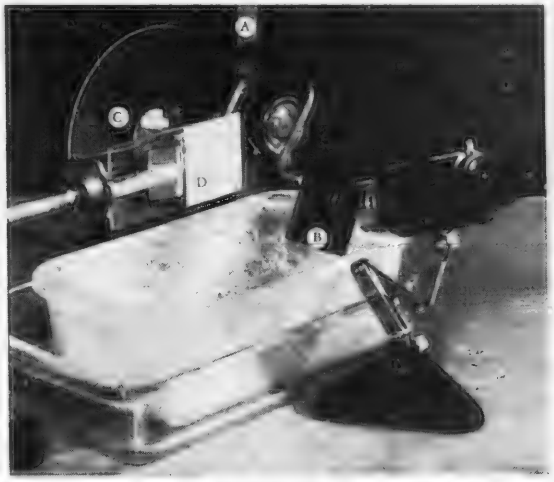

Fig. 1.—Apparatus for determination of wettability by means of contact angle showing supporting stand (A), block (B), protractor (C), and reflection target (D).

ALTHOUGH CONDITIONS ADAPTED to the satisfactory gluing of our more common woods are reasonably well established, they have, for the most part, been determined empirically, and relatively few studies have been made on the influence of the basic wood properties on adhesion.

In conjunction with basic wood properties, several authors (10, 13, 14)[2] have indicated relationships between glue joint strength and specific gravity. The strength of a well-bonded glue joint increases with increasing specific gravity. Wood failure values, on the other hand, tend to decrease with increasing specific gravity, because of the increasing demand placed on the glue bond by the stronger, more dense wood.

Of particular importance from the standpoint of the present study is the fact that some woods, in relation to woods of similar specific gravity, are low in shear strength, in wood failure, or in both. These deviations from the general trend suggest the influence of other factors.

Among these factors is wettability, that is, the degree to which a wood is wetted by an adhesive. DeBruyne and Houwink (5), in their discussion of the theory of adhesion, state that a necessary prerequisite to gluing is wetting of the surface by the adhesive. They further state that the primary wetting is done by the solvent of a solution containing a high-molecular-

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[1] Second-place winner, 1959 Wood Award contest.

[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

weight substance. Browne (2, 3) indicated as long ago as 1929 that the mechanism of adhesion was specific and not mechanical, and implied the necessity for molecular affinity between adhesive and adherent. Horioka and co-workers (9) measured the contact angle of adhesives on some woods, and reported that water-dispersed adhesives are better than alcohol-dispersed adhesives with respect to wettability. All of these studies indicate the importance of wettability to good adhesion.

Another wood property of potential importance is acidity. Gray (8) suggests that parana pine is difficult to glue because of its high alkalinity. He has measured the pH of a wide variety of woods and found much variation both between and within species. In spite of its possible significance, studies of the influence of wood acidity upon the quality of the initial glue bond appear to have been neglected. Truax (14), in discussing gluing problems in 1929, prior to the advent of synthetic resin adhesives, mentioned that the free alkali of certain glues might counteract the effect of extractives. Wood acidity would appear to have possible significant effects, particularly with synthetic resin adhesives that are dependent upon acidic or basic catalysts for their cure.

Specific gravity, acidity (pH), and wettability of wood have potential significance in an investigation of adhesion. The present study was undertaken in an effort to determine their effects upon the quality of the initial glue bond. A further aim was to investigate the possibility of modifying gluing procedures so as to counteract the effect of wood characteristics that tend to interfere with adhesion. Variation in assembly time was chosen for its possible ameliorating effect upon the quality of glue bonds obtained with woods that show wide variation in these physical and chemical properties.

In any gluing study, there must be a glue-bond evaluator. Shear strength is most commonly used, although wood failure is often mentioned. Northcott (11) and Truax (14) have indicated dissatisfaction with wood failure as a criterion of glue-joint quality. Both favor shear strength. A third method of determining glue-joint quality is a shear ratio, in which the shear strength of the glued block is related to the shear strength of solid wood. All three evaluators, shear strength, wood failure, and shear ratio, were compared in this study.

The objectives of this study can be summarized as:

1) The determination of the relationships of specific gravity, pH, and wettability of wood with the quality of adhesive bonds.
2) The determination of the effect of assembly time on adhesion in relation to specific gravity, wettability, and pH.
3) The comparison of three glue-bond evaluators: shear strength, wood failure, and shear ratio.

The procedure was to glue 22 species of hardwoods, which exhibit a wide variation in properties, with two synthetic resins and at a variety of assembly times, then shear test the glued blocks, and analyze the results to determine glue joint quality relationships with pH, wettability and specific gravity.

WHAT THIS RESEARCH MEANS

The gluing of wood has proceeded for generations, but there are still many problems to be solved. In particular, lengthwise gluing of wood leaves much to be desired, and the gluing of some species is not completely successful. Regardless of grain orientation, the desired result is a bond as strong, or stronger, than the wood itself.

Close examination of the properties that affect adhesion will lead to improved gluing of wood in all directions. For hard-to-glue species, it might be logical to attempt to isolate the universal properties that affect adhesion by investigating many woods with a wide range of properties. This approach is contrary to that which attempts to determine optimum gluing procedures for each species of wood individually.

As a greater variety of species come into use and as competition from other materials force increased use of adhesives, the empirical, species by species, investigations may prove to be less useful than a basic, theoretical approach, such as that reported here.

Procedure

Selection of Species: The 22 hardwoods used in this study were chosen on the basis of wide variation in pH and wettability over an extremely wide range of specific gravity. The species are listed in Table E, together with their values for specific gravity, pH, and wettability (by two methods) as determined in this study.

Preparation of Material for Gluing: The material used in this study was obtained from air-dry, flat-sawn lumber. The moisture content of this material was found to be approximately 12 percent, and it was subsequently maintained at that level throughout machining, gluing, conditioning, and testing. The maximum allowable slope of grain was 1 in 12, and all material was defect-free heartwood.

Eight 4-foot sticks, 2 inches wide, were cut for each species. Subsequent cutting was performed so that the 4 assembly times were from endmatched material, and the half-blocks that were glued together were sidematched. After planing to ¾ inch thickness, the 4-foot sticks were cut to 12 inches. In this way, 16 laminated blocks were prepared for each species. The cut-off ends of these sticks were retained for use in pH and wettability (mm) measurements.

Preparation of Adhesives and Gluing: The two adhesives used in this study were Perkins L–100 liquid urea-formaldehyde resin, with catalyst S–120, and Koppers Pencolite G–1260, a two-component resorcinol-phenol resin. Except for closed assembly time, the two adhesives were used in accordance with the manufacturer's recommendations. The quantities of resin and catalyst were accurately measured and, because a fresh mix of adhesive was prepared for each assembly time, the pot life never exceeded 30 minutes. Both adhesives were spread at the rate of 60 pounds per 1000 square feet of glue line. The adhesives were weighed on each laminate, 2-¼ grams per surface, and evenly spread with a rubber roller.

The urea resin was cured at gluing-room temperatures that ranged from 76° to 82° F. The manufacturer's recommended maximum closed assembly time is 20 minutes at an ambient temperature of 70° to 75° F. The actual assembly times used are listed below:

Assembly time (minutes)	Percentage of manufacturer's recommended maximum
6.5	33
13.0	67
26.0	133
52.0	267

The resorcinol-phenol resin was cured at 150° F. (glue-line temperature) for 6 hours in a humidity-and temperature-controlled cabinet. The manufacturer's recommended maximum assembly time is 3 hours at 70° to 80° F. The closed assembly times actually used were based on a percentage of the manufacturer's recommended time according to the table listed below:

Assembly time (hours)	Percentage of manufacturer's recommended maximum
1	33
2	67
4	133
8	267

With both resins, pressure was applied by means of rocker-head screw clamps that had previously been calibrated with a torque wrench and a compressometer to give the desired glue-line pressures. The following

pressures, correlated with specific gravity, were used:

Specific gravity	Pressure (psi)
0.36–0.45	150
0.46–0.55	200
0.56 and above	300

After they were cured, the assemblies were end coated with a sealer and conditioned for 7 days at an EMC of 12 percent.

Machining of Test Specimens: Each 2-ply laminated block was cut to a 1-½ inch width and an 11-inch length, and 5 shear blocks were then cut from the large block. The shear area of each test block was 2.25 square inches. The shear blocks were stored under 12 per cent EMC conditions prior to testing.

Testing of Shear Blocks: The shear blocks were tested to failure by means of the standard glue block shearing tool and a Baldwin hydraulic testing machine. Testing speed was 0.015 inch per minute. Maximum glue-joint shear strength in psi and estimated percentage of wood failure were recorded for each specimen.

Of the five shear blocks representing a laminated block, a half-block that exhibited wood failure was selected as a moisture content and specific gravity specimen. The specimen was weighed on a torsion balance and its volume determined with a mercury volume meter. The moisture content and specific gravity (O.D. weight/O.D. volume) were recorded. Another shear block half was selected for the contact angle wettability determination, for which the procedure is described below.

In addition to shear strength and percentage of wood failure, a third glue-bond evaluator, shear ratio, was used. Shear ratio is the glue-block shear strength in psi divided by the shear strength of solid wood in psi. Tangential shear values were used in both numerator and denominator, the tangential solid wood shear values being obtained from unpublished Yale data in the case of the tropical woods and from the Forest Products Laboratory in the case of the native woods.

To account for specific gravity differences between the wood tested for solid wood shear and that represented in the glue blocks, the 22 solid wood shear values and their corresponding specific gravity values were statistically fitted with a straight line. A test for significant curvature yielded negative results. The solid wood shear values were then adjusted along this linear slope to the specific gravity of the glue-block shear values, and the shear ratio was then calculated. The shear ratio thus indicates the extent to which the glue bond has developed the strength of the solid wood.

Table 1.—SPECIFIC GRAVITY (O.D. WEIGHT/O.D. VOLUME), pH, WETTABILITY (CAPILLARY RISE, MM.) AND WETTABILITY (COSINE OF CONTACT ANGLE) FOR 22 WOODS OF DOMESTIC AND TROPICAL AMERICAN ORIGIN

Common name	Scientific name	Specific gravity	pH	Wettability (mm)	Wettability (Cosine)
Cedro Espino	*Bombacopsis quinata*	0.40	5.26	0.0	0.321
Butternut	*Juglans cinerea*	0.42	3.97	17.9	0.616
Primavera	*Tabebuia donnell-smithii*	0.43	5.77	12.1	0.700
Yekoro	*Ocotea schomburgkiana*	0.44	4.30	0.0	0.532
Aspen	*Populus tremuloides*	0.44	4.64	8.6	0.785
Yellow Poplar	*Liriodendron tulipifera*	0.46	5.03	17.1	0.624
Determa	*Ocotea rubra*	0.49	3.72	0.0	0.367
Vaco	*Magnolia sororum*	0.56	5.49	15.6	0.654
White Oak	*Quercus alba*	0.62	3.54	9.2	0.640
Red Oak	*Quercus rubra*	0.62	3.48	12.8	0.643
Fiddlewood	*Vitex gaumeri*	0.63	5.55	10.9	0.859
Brazil Nut	*Bertholletia excelsa*	0.65	3.52	0.0	0.389
Pau Rosa	*Aniba duckei*	0.69	3.93	8.9	0.582
Angelique	*Dicorynia paraensis*	0.72	4.65	15.4	0.778
Mylady	*Aspidosperma cruentum*	0.75	4.42	16.1	0.723
Purpleheart	*Peltogyne venosa*	0.78	5.32	9.8	0.648
Muirá-juba	*Apuleia molaris*	0.84	4.84	2.1	0.386
Timbauba	*Enterolobium schomburgkii*	0.93	5.09	2.3	0.456
Acapu	*Vouacapoua americana*	0.96	4.85	0.7	—0.006
Greenheart	*Ocotea rodiaei*	1.02	5.15	0.0	0.358
Almendro	*Coumarouna oleifera*	1.04	4.56	13.9	0.428
Bannia	*Swartzia bannia*	1.16	4.25	8.8	0.646

Wettability Determination (Contact Angle): Wettability is defined as the cosine of the advancing angle of contact of water with wood as measured by the inclined plate method described by Adam (1). The plate of wood used to read the angle was a representative shear-block half that had been resurfaced on a jointer shortly before the wettability determination. The contact angle measuring apparatus is shown in Fig. 1. It consists of a supporting stand (A), which permits the test block (B) to be raised, lowered and changed in angle. Initially, the block is indexed on a shaft with pointer so that the angle of the block can be read from a protractor scale (C) also fastened to the stand.

The block was lowered into distilled water until the fresh face was slightly immersed at the lower end. The reflection on a flat reflection target (D) of a slit of light directed at the wood-water interface indicated whether the water surface curved upward or downward where it met the wood. If the reflection was bent, which would indicate a meniscus at the interface, the block was raised, its angle changed and the block relowered, until the reflection of the slit of light indicated that the water surface was plane at the point where it met the wood. The contact angle was then read from the protractor. The angle was read four times on the face of each block, and the average value was recorded as the contact angle for that particular stick. The values shown in Table 1 for each species represent the average of the 4 stick values, 2 for urea and 2 for resorcinol-phenol material.

pH Determination: In preparation for pH determination, the end trim taken from each stick was reduced to wood flour in a Mikro-Samplmill. Care was taken to avoid surface contamination. After a conditioning period, the pH of a portion of the flour was determined by mixing five grams of the wood flour with 50 grams of distilled water. The mixture was allowed to stand for 10 minutes before the pH was determined with a standardized Beckman pH meter. The pH was recorded after about a minute when the meter indicated a constant value. The average pH of the four sticks of a species is indicated in Table 1.

Wettability (Capillary Rise in mm.) The wettability for the samples of each species was determined on a portion of the same material used for the pH determination. A sample of the

Table 2.—CALCULATIONS USED IN COMPUTING MULTI-VARIATE REGRESSION ANALYSIS OF SHEAR STRENGTH VERSUS SPECIFIC GRAVITY FOR RESORCINOL-PHENOL RESIN

Assembly time	Source of variation	Degrees of freedom	Sum of squares	Mean square	F
1 Hour	Slope	1		13634669.80	148.87 (HS)[1]
	Error	42	3846809.82	91590.71	
2 Hours	Slope	1		13769471.40	185.12 (HS)
	Error	42	3124044.00	74382.00	
4 Hours	Slope	1		6575948.70	121.29 (HS)
	Error	42	2277040.08	54215.24	
8 Hours	Slope	1		8655574.70	36.92 (HS)
	Error	38	8909975.14	234473.03	
Combined	Slope	1		41796651.00	377.51 (HS)
	Bet. Slopes	3	839013.60	279671.20	2.525 (NS)
	Bet. Means	3	4661898.00	1553966.00	14.04 (HS)
	Error	164	18157404.70	110715.88	

[1](HS) indicates significance at the 1% level of probability.
(NS) indicates not significant, and (S) indicates significance at the 5% level of probability throughout this report.

wood flour was tamped into a small glass tube (3 mm. I.D.). The tube was then immersed in water to a depth of ¼ inch, and the height of capillary rise of the water in the wood flour was measured after one minute. The wettability of a sample, then, is the height of rise (mm). of the water in the wood flour. The average wettability of the four sticks of each species is indicated in Table 1.

Treatment of Data

The initial wettability determination method with wood flour received a thorough and critical examination because a considerable number of the woods exhibited "zero" wettability as shown in Table 1. Admittedly, these woods are all low in wettability. It was felt, however, that they probably differed in their wetting characteristics, and that a more sensitive wettability method ought to distinguish between them. Upon further investigation, it was found that the species used in this study fractioned differently in the Mikro–Samplmill; some produced a granular flour while others produced a fibriform flour. It seemed especially disadvantageous to employ a capillary-rise type of wettability measurement in view of the fractionating differences.

The later wettability method, based on the inclined plate, is simple to conduct and gives a measure of the relative wettability of the woods involved. In initial investigations, reproductibility of results was achieved, although much variation within a species was noted. For the 88 sticks of the 22 woods involved, the correlation of the two wettability methods was good; the correlation coefficient (0.650) was highly significant. In this respect, the two methods support each other and lend credence to the belief that both wettability measures indicate the attraction of wood for liquid water. Subsequent statistical analysis of the gluing data was carried through with only contact-angle wettability.

The original intention in data treatment was to carry through a straightforward multi-variate analysis with both adhesives and all three glue-bond evaluators, to make a total of six rather distinct analyses. A critical examination of the scatter diagrams of strength versus specific gravity and percentage wood failure versus specific gravity for both adhesives revealed a sharp break in the trend of the dependent variable at about 0.80 specific gravity. This break can be noticed in Figs. 2 and 3, especially with the data for urea in Fig. 2.

The hypothesis was developed that, in the low-density region, wood shear strength is relatively low and does not stress the bond to a great extent. The consequences of this are that percentage wood failure is high, with little relationship with specific gravity, wettability, or pH, and that the range in shear strength is largely accounted for by specific gravity. It is not expected that pH and wettability would be related to shear strength when the wood is failing. On the other hand, in the high-density region, wood failure values should be lower and more closely related to pH and wettability while shear strengths become less dependent on specific gravity and more related to pH and wettability. Shear ratio should follow shear strength.

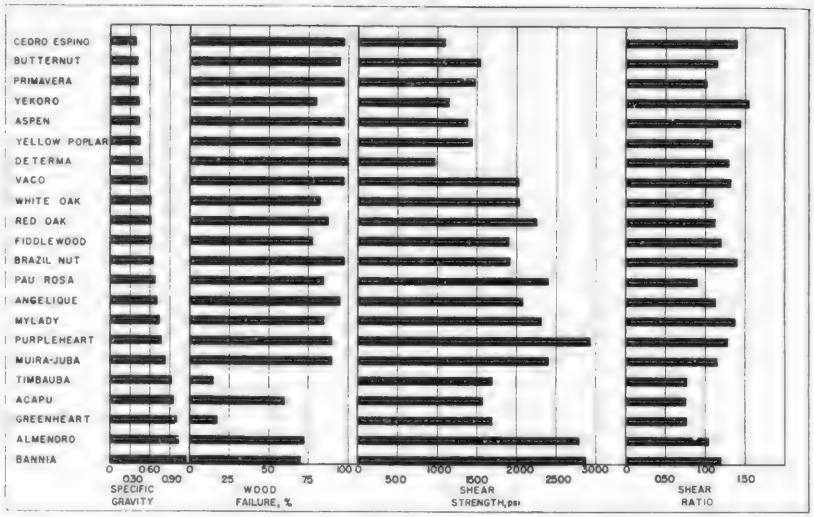

Fig. 2.—Average results of shear tests on joints of foreign and domestic hardwoods bonded with urea-formaldehyde resin with 6.5 minutes closed assembly time.

To check the above-described hypothesis, an attempt was made to determine statistically a breaking point in the data so that a separate analysis could be made for the material above the breaking point and that below. No statistical basis could be found for splitting the resorcinal-phenol data into two parts, and the data were not split in the subsequent analysis. With the urea data, a breaking point was determined at 0.80 specific gravity. By splitting the data at this point, the linear regression of shear strength versus specific gravity accounts for a larger percentage of the total variance in shear strength in the lower region than is accounted for by splitting the data at any other point or by considering the data as a whole.

The values used in the analysis are averages for 5 shear blocks, except in a few cases where only 3 blocks were used.

In the analysis of the data, linear regressions were used in every case because there seemed to be no justification for using any more complex relationship. In the majority of cases, the scatter is such that a line fits about as

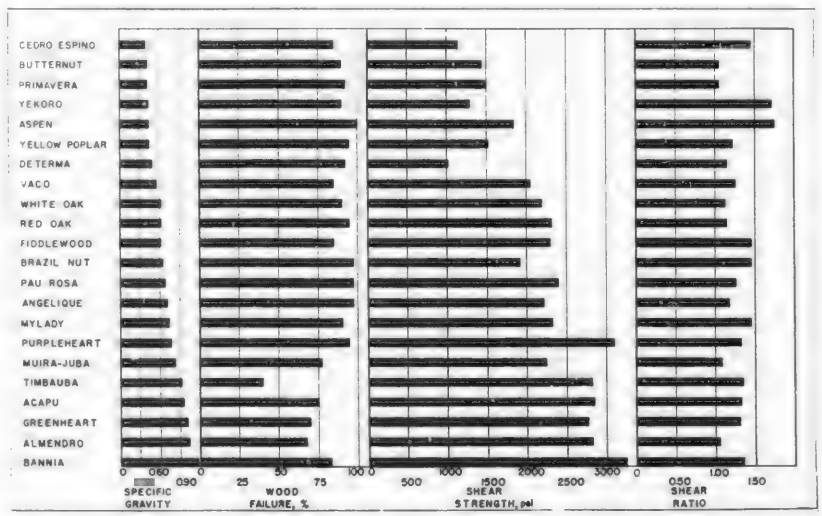

Fig. 3.—Average results of shear tests on joints of foreign and domestic hardwoods bonded with resorcinol-phenol-formaldehyde resin with 1.0 hour closed assembly time.

well as a curve would. For each of the 2 glues, the 4 assembly times were regarded as treatments and the particular glue bond evaluator was regarded as dependent on the independent, yet related, covariates, pH, wettability, and specific gravity. An idea of the calculations and method used can be determined from Table 2.

Results

The results of the study are presented in Figs. 4 through 9. The graphs indicate the relationships for all three glue-bond evaluators with specific gravity, pH, and wettability. Slopes are drawn only where the slope has been found to be significant at the 5 percent level of significance or better. If the relationship was not significant, it either was not presented or it was drawn horizontally through the mean of the dependent variable.

With the urea resin, the split doubled the number of means and slopes about which the dependent variable could vary, with the net result that the lines fit the data very well and a very high percentage of the total variance is accounted for. Each portion of the data is drawn across the area corresponding to the data, region "A" being the material below 0.80 specific gravity and region "B" being the material above 0.80 specific gravity. While the total range of each region is the same, approximately 0.40 specific gravity units, the data in region "A" were formed from 122 values while the data of region "B" were formed from only 50.

Examination of the data indicate that assembly time exerted no significant effect in the low-density region, while in the high densities it was significant. This is in keeping with the hypothesis that gluing is not as critical with low density woods, the principal influence is one of specific gravity.

The particular arrangement of the assembly times for the high-density data, the downward trend of strength, wood failure and shear ratio with increasing assembly time, with the exception of the superior 52 minute assembly time, was surprising; so much so that another study was made to check this phenomenon.

In the subsequent study, the material of the three species that exhibited the irregular assembly time effect to the greatest extent. Timbauba, Almendro, and Acapu, was glued in the same manner as that of the earlier study. The blocks were tested, and shear strength and percentage of wood failure were recorded. An analysis of variance was applied to the shear-strength data, with the result that the effect of species was highly significant as was the effect of assembly time. The

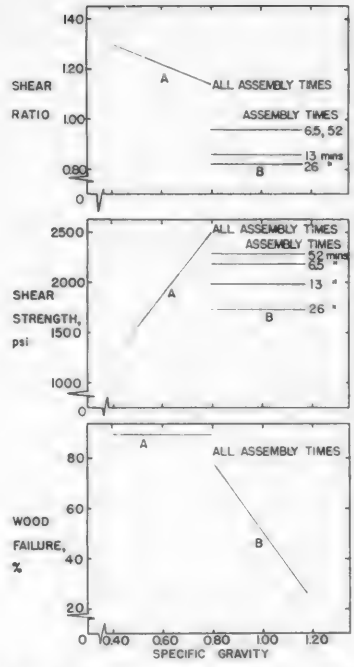

Fig. 4.—Relationships of shear ratio, shear strength, and percentage wood failure with specific gravity for 22 woods glued with urea-formaldehyde resin. Region "A" denotes material with 0.80 specific gravity and below while region "B" denotes material with above 0.80 specific gravity.

Considering shear ratio, in region "A" the F-ratio is 12.11 (HS), while in region "B", where shear ratio is adjusted for the effects of pH and wettability, the F-ratio is less than one (NS).

Considering shear strength, in region "A" the F-ratio is 242.9 (HS), while in region "B", where shear strength is adjusted for the effects of pH and wettability, the F-ratio is less than one (NS).

In the case of percentage of wood failure, which is adjusted for the effect of wettability in region "A", the F-ratio is 1.255 (NS), while in region "B", where percentage of wood failure is adjusted for the effect of pH, the F-ratio is 38.09 (HS).

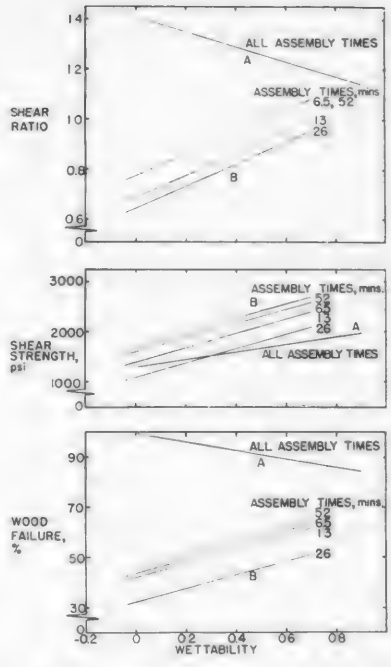

Fig. 5.—Relationships of shear ratio, shear strength, and percentage of wood failure to wettability (cosine of contact angle) for 22 woods glued with urea-formaldehyde resin. Region "A" denotes material with 0.80 specific gravity and below while region "B" denotes material with above 0.80 specific gravity.

Considering shear ratio, in region "A", where shear ratio is adjusted for the effect of specific gravity, the F-ratio is 4.918 (S) while in region "B", where shear ratio is adjusted for the effect of pH, the F-ratio is 11.73 (HS).

Considering shear strength, in region "A", where shear strength is adjusted for the effect of specific gravity, the F-ratio is 21.48 (HS), while in region "B", where shear strength is adjusted for the effect of pH, the F-ratio is 22.43 (HS).

In the case of percentage wood failure, the F-ratio in region "A" is 9.321 (HS) while in region "B", where percentage wood failure is adjusted for the effects of pH and specific gravity, the F-ratio is 4.490 (S).

means of the assembly times for this study, together with those of the original study, are presented below.

	Assembly times (minutes)			
	6.5	13.0	26.0	52.0
High-density woods Original-data means	2172	1962	1800	2254
High-density woods Check-data means for 3 species	2374	2304	2503	2675

Discussion of Results

One of the most surprising results of the study, and one that deserves first discussion, is the relationship of assembly time to glue-bond quality shown for the urea-formaldehyde resin. Results obtained with low-density material indicate that closed assembly times somewhat short of three times the manufacturer's recommended maximum give no decrease in glue-bond quality. The results with the high-density material are more surprising in that a significant increase in glue-bond quality resulted with the long assembly time. The latter result was substantiated in the check test of three high-density species.

No evidence of lack of squeeze-out or of dried joints was observed at any of the assembly times in the urea-formaldehyde gluing operation. The manufacturer's data sheet (12) helps to explain this behaviour. In accordance with these instructions, a heavy-bodied mix was used. The instructions state further that, in gluing wood of high density, a delay in assembly time will help prevent excessive squeeze-out or starved-joint conditions. Thus it seems reasonable that this mix is somewhat slow compared to some other cold-set ureas and that excellent quality glue bonds will result when Perkins L–1000

with catalyst S–120 is used in accordance with instructions even at closed assembly times of almost one hour.

The results of the analysis of the urea-formaldehyde resin data indicate that the variables that have the greatest effect upon glue-bond quality above 0.80 specific gravity are different from those that predominate below. In the low-density region, specific gravity is the dominant factor with shear strength. Insofar as the average wood failure in this group of data was 89.5 percent, the strength of the glued blocks was principally controlled by their solid wood shear strength. The latter is, of course, very closely related to specific gravity.

The negative relationship of shear ratio versus specific gravity shown in Fig. 4 requires explanation, especially so when joint shear strength increases with density over the same range. When specific gravity increases from 0.40 to 0.80, solid wood shear strength increases at a certain rate. For the shear ratio to increase over this same range would require that glued block shear strength increase with increasing specific gravity by more than a fixed ratio with solid wood shear strength. The results indicate that the glued block shear strength does not increase that fast. Once this point is realized, the results become coherent.

A further point concerns the shear ratio versus shear strength relationship in this region. As shown in Fig. 4, the two glue-bond evaluators, shear strength and shear ratio, appear to contradict each other in this specific gravity range. As specific gravity increases, glued block shear strength also increases. The extent to which the glued block develops the full shear strength of solid wood becomes less and less, however. Percentage wood failure was very high in this region, and had no significant relationship with specific gravity, shear strength, or shear ratio.

In the low specific gravity region, the wood quality that tended to show a secondary relationship was wettability. The relationship with shear strength shown in Fig. 5 is logical. Below 0.80 specific gravity, shear strength (after adjustment for the effect of specific gravity) increases with increasing wettability. The relationship is stronger in the high-density region (where the adjustment is for the effect of pH and not for specific gravity) than in the low-density region.

The wettability relationship with the other glue-bond evaluators is negative in the low-density region. The data have been carefully re-examined to provide possible explanations for the contradictions. As far as the wood failure results are concerned, wettability evidenced a stronger effect than specific gravity and thus was handled first statistically. Wettability and specific gravity have a positive correlation (interaction), thus the relationship indicated for wettability in Fig. 5 might be truly one of specific gravity. Actually no relationship of either kind would be expected in this region because of the high level of wood failure; however it might be more reasonable to assume that the negative relationship discovered is one of specific gravity rather than one of wettability.

The negative relationship of shear ratio to wettability in the low-density region is to be expected because, as indicated previously, shear strength and shear ratio contradict each other in this specific gravity range.

In the low-density range, the pH versus glue-bond evaluator relationship can be explained on the basis that pH (a wood property that influences adhesion) can exert no influence so long as wood is failing and the glue bond is not highly stressed. Wood failure was uniformly high in this range. It might be well to indicate that specific gravity accounted for 67.9 percent of the variance in glued-block shear strength in this region, while overall for the 22 woods involved, specific gravity accounted for 73.8 percent of the solid wood shear strength. So long as wood is failing, the predominant influence is one of specific gravity.

The picture above 0.80 specific gravity is different. Here specific gravity has no significant relationship to either shear strength or shear ratio. The wood failure versus specific gravity relationship is negative. Wettability has a positive relationship to all of the glue-bond evaluators in the high-density region; that is, glue-bond quality increases as wettability increases. Increasing wettability is denoted by increasing cosine of contact angle.

Of the three covariates, wettability, pH, and specific gravity in the high-density region, pH revealed the strongest relationship. The pH accounts for 39.0 percent of the variance in shear strength, 42.8 percent of the variance in wood failure, and 32.7 percent of the variance in shear ratio. The extent of these relationships can be seen in

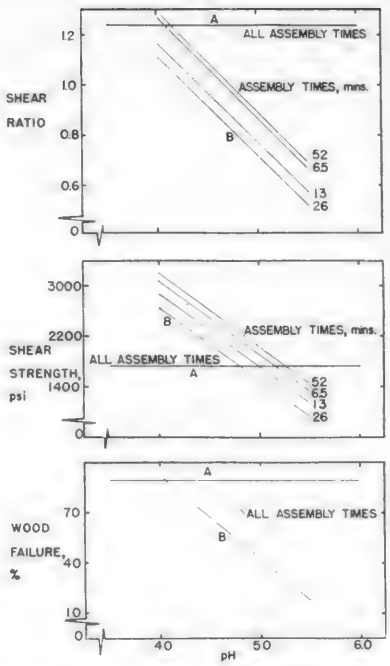

Fig. 6.—Relationships of shear ratio, shear strength, and percentage wood failure to pH for 22 woods glued with urea-formaldehyde resin. Region "A" denotes material with 0.80 specific gravity and below, while region "B" denotes material with above 0.80 specific gravity.

Considering shear ratio, in region "A", where shear ratio is adjusted for the effects of specific gravity and wettability, the F-ratio is 2.815 (NS), while in region "B", the F-ratio is 26.39 (HS).

Considering shear strength, in region "A", where shear strength is adjusted for the effects of specific gravity and wettability, the F-ratio is 3.302 (NS), while in region "B", the F-ratio is 36.70 (HS).

In the case of percentage wood failure which is adjusted for the effect of wettability in region "A", the F-ratio is 3.833 (NS), while in region "B" the F-ratio is 34.80 (HS).

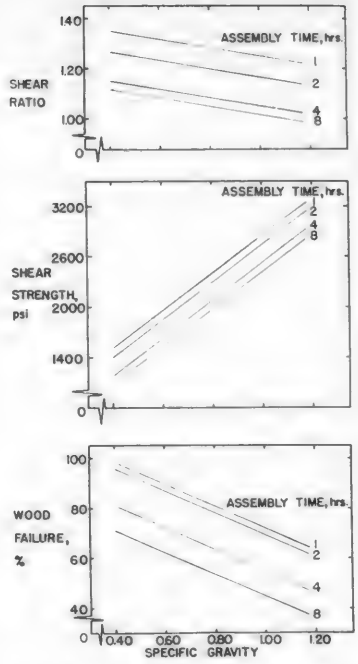

Fig. 7.—Relationships of shear ratio, shear strength, and percentage of wood failure to specific gravity for 22 woods glued with resorcinol-phenol-formaldehyde resin.

In the case of shear ratio, the F-ratio is 6.294 (S).

In the case of shear strength, the F-ratio is 377.5 (HS).

In the case of percentage of wood failure, the F-ratio is 59.53 (HS).

Fig. 6. These relationships are not surprising if one considers that the woods with high pH probably exert a buffering and neutralizing effect on the acid catalyst of the glue. According to the wood-failure results, there is more glue-line failure and it might be presumed that, with these relatively fresh and unaged joints, the pH of the wood influences the amount and quality of the polymerization and bonding to the wood surface.

Although work at the Forest Products Laboratory (8) during World War II indicated deleterious effects of low pH, the two studies are not comparable. The work at that time was concerned with durability of glue joints rather than initial quality of bond as discussed here. In regard to pH, the three glue-bond evaluators agree as they do throughout this high-density region. It appears, that so long as glue bonds are failing, glue-line quality can be evaluated by any of the three methods, shear strength, shear ratio, or percentage of wood failure.

No statistical basis could be found for splitting the resorcinol-phenol data, although Fig. 3 seems to indicate two zones. The breaking point is not nearly so sharp as with the urea data of Fig. 2. Specific gravity (Fig. 7) accounted for 63.4 percent of the total variance in shear strength and was the dominant factor. The relationship of percentage of wood failure to specific gravity is negative, as expected. The shear ratio versus specific gravity relationship is again contrary to that shown by the shear strength versus specific gravity data. The situation is analogous to that of the urea data below 0.80 specific gravity. Although glue-block shear strength increases with increasing specific gravity, it does not increase fast enough to maintain an increasing ratio with solid wood shear strength.

In regard to the pH relationships of Fig. 8, shear ratio was not significantly affected, but the shear strength and percentage of wood failure data appeared to be contradictory. The shear strength relationship was found to be positive, and the percentage of wood failure relationship negative. This anomaly deserved further consideration. Since the hypothesis of two specific-gravity-based regions had been found useful in analyzing the urea resin data, the resoricinol-phenol shear strength versus pH data were analyzed separately according to the specific gravity regions (split at 0.80). This split analysis revealed that the apparent trend of increasing shear strength with increasing pH was made up of two decreasing trends, one shown by material above 0.80 and the other by material below 0.80 specific gravity. Shear strength decreases with increasing pH

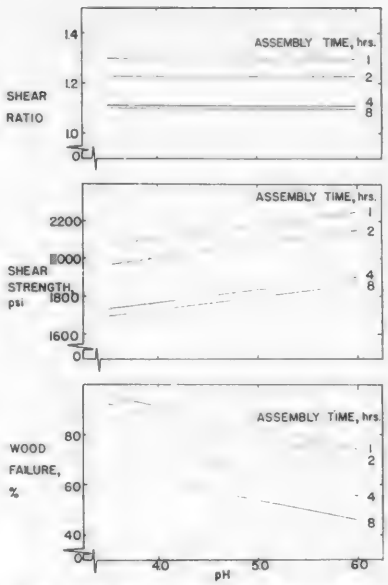

Fig. 8.—Relationships of shear ratio, shear strength, and percentage of wood failure to pH for 22 woods glued with resorcinol-phenol-formaldehyde resin.

In the case of shear ratio, after adjusting for the effects of specific gravity and wettability the F-ratio is less than one (NS).

In the case of shear strength, after adjusting for the effects of specific gravity and wettability the F-ratio is 4.448 (S).

In the case of percentage of wood failure, after adjusting for the effect of specific gravity the F-ratio is 18.87 (HS).

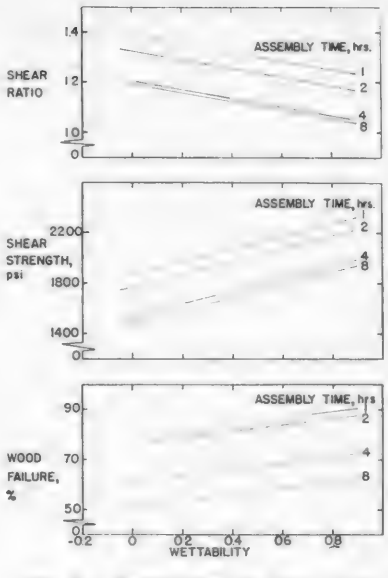

Fig. 9.—Relationships of shear ratio, shear strength, and percentage of wood failure to wettability (cosine of contact angle) for 22 woods glued with resorcinol-phenol-formaldehyde resin.

In the case of shear ratio, after adjusting for the effect of specific gravity the F-ratio is 4.983 (S).

In the case of shear strength, after adjusting for the effect of specific gravity the F-ratio is 16.45 (HS).

In the case of percentage of wood failure after adjusting for the effect of specific gravity and pH the F-ratio is 4.025 (S).

in both regions, with the greatest decline occuring in the high-density region. The mechanism is evidently not so strong as the one that operates with urea resin. Although the resorcinol-phenol resin is not acid catalyzed, it seems reasonable to conjecture that the resin system may be influenced by a change in pH. Some extractives that interfere with gluing may be of high pH. The pH apparently does have an effect on the degree to which the resorcinol-phenol adhesive bonds to the wood.

The wood failure and shear strength versus wettability data of Fig. 9 are in good agreement, but the slope of the shear ratio relationship is again negative. As seen from other data in this study, the trend of shear ratio is one of contradiction with shear strength data when wood failure values are high. When gluing conditions are critical, increased wettability does lead to better adhesion with resorcinol-phenol resin adhesives.

A noteworthy and consistent relationship shown throughout the study is that between assembly times and glue-bond quality with the resorcinol-phenol resin. the assembly times are significantly different and they fall in a coherent order, the shortest assembly time resulting in the best glue bonds, followed by a trend of decreasing glue joint quality with increasing time. The drop, as measured in shear strength or wood failure, is substantial. Resorcinol-phenol gluing of optimum quality obviously requires that the manufacturer's closed assembly time recommendations be followed.

Comparisons between the resorcinol-phenol and the urea data are necessarily complicated by the differences in the handling of the data. Although it may not be apparent from Figs. 4 through 9, careful examination of Figs. 2 and 3 will reveal a generally higher level of quality of the resorcinol-phenol joints. Any comparison of the relative shear strengths, precentage of wood failures, or shear ratios obtained with the two resins, should take into account the differences in the methods of cure employed with the two adhesives.

In terms of assembly time relative to manufacturer's recommended maximum, prolonged assembly time results in decreased strength of the resorcinol-phenol joints. This was not the case with the urea resin used in this study. Time-wise, it should be noted, the resorcinol-phenol assembly times begin about where the urea assembly times end.

Some differences in the effect of the wood properties upon the two adhe-

sives are notable. Specific gravity accounts for more of the variation encountered in glue joints made with the resorcinol-phenol than in those made with urea resin. In other words, the resorcinol-phenol resin bonds are limited, to a greater extent than with the urea resin, by solid wood shear strength, which is related to specific gravity. Both pH and wettability exert a greater influence upon glue-bond quality with the urea resin. With regard to pH, it may be argued that the urea resin system is a more delicately balanced system. When wettability is considered, it is well within reason to suppose that the heat-curing might partially negate the different wettability effects of various woods. It is reasonable to expect that heat-cured resins would be less sensitive to changes and variation in wettability of the woods involved insofar as increased temperature reduces the surface tension of liquids. The decline in effect of wettability and pH with resorcinol-phenol resin is probably a result of a combination of the above mentioned effects. Certainly the increased quality of the resorcinol-phenol resin joints is a result of less susceptibility to such adhesion-related properties as pH and wettability. The consequence is a greater dependence on solid wood shear strength and specific gravity with the resorcinol-phenol resin joints than with the urea resin joints.

With both the urea and the resorcinol-phenol data, assembly time changed none of the effects of pH or wettability. In all cases, the slope of the relationship for the four assembly times was the same.

The three glue-bond evaluators, shear strength, percentage of wood failure, and shear ratio, are in fairly close agreement throughout the study. Areas of disagreement have already been discussed. The shear ratio, as here defined and used, was fairly successful. The difficulties mentioned are probably more a result of interpretation than of fault with the evaluator. The shear ratio would undoubtedly be most advantageous when both the numerator and denominator were formed from tests of matched material. In that way, excessive variation would be eliminated and the ratio would give a measure of the degree to which the shear strength of the actual wood being glued is developed.

Shear strength and percentage of wood failure values are generally in agreement. When wood is failing, percentage wood failure is high and glue-block shear strength is limited by the solid wood shear strength. The potential of the glue bond remains untested. In this case, not much can be said about the glue-bond shear strength except that it has exceeded a certain minimum. Probably the use of both of these evlauators, together with judicious interpretation of the results, gives the truest picture of glue-bond quality.

Conclusions

Positive conclusions from the above study must necessarily be limited to the particular adhesives and species investigated. It is felt that the relationships revealed at this time are only the first in a series of continuing studies that will eventually enable improvement in the gluing of all species of wood.

The study resulted in the following conclusions:

In gluing with Perkins L–100 urea-formaldehyde resin and catalyst S–120, closed assembly times as long as 52 minutes, almost three times the maximum recommended by the manufacturer, are not deleterious to glue-bond quality, and with some high-density woods actually increase the quality of bond. With Koppers Penacolite G–1260, a resorcinol-phenol resin, closed assembly times beyond that recommended by the manufacturer result in inferior glue-bonds.

Closed assembly times of 6.5 to 52.0 minutes with urea resin and 1 to 8 hours with resorcinol-phenol resin have no effect on the basic relationships of pH, wettability, and specific gravity to glue-bond quality.

Of the above three variables studied for their effect on quality of glue bonds, specific gravity is dominant in the low-density region with urea resin, and throughout the entire range of density tested in the case of the resorcinol-phenol resin. Specific gravity was followed, in order of their effects, by wettability and pH over the same range. In the high-density region with urea glue-bonds, pH is dominant, followed in order of their effects on quality by wettability and specific gravity.

In general, specific gravity is more important, and pH and wettability less important, with resorcinol-phenol glue bonds than with those glued with urea resin. The resorcinol-phenol adhesive is more consistently limited by solid wood shear strength, which is, in turn, dependent upon specific gravity.

As long as wood failure is high, shear ratio may contradict shear strength as a measure of glue-bond quality, especially when the bulk of the data are collected between species rather than within. In all other respects, shear ratio, shear strength, and percentage of wood failure are in agreement as to glue-bond quality.

Shear ratio is useful as a glue-bond evaluator, and may become more so with increased familiarity, especially in an experiment particularly designed for its use. A design of this sort would be most efficient if provision were made for the numerator and denominator of the ratio to be formed from results of tests on matched material, and if the bulk of the testing was within species rather than between.

This study has positively demonstrated that pH, wettability, and specific gravity are closely related to glue-bond quality. Before this knowledge can be utilized, the exact nature of these relationships must be clarified by further investigation. It is hoped that the result of these investigations will be a more fundamental knowledge of the properties of woods that influence adhesion.

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Fig. 1.—(A), Enzymatic brown stain in the sapwood; (B), brown stain in the heartwood after disappearing from the sapwood; (C), brown stain around old shake damage limited by azide dip.

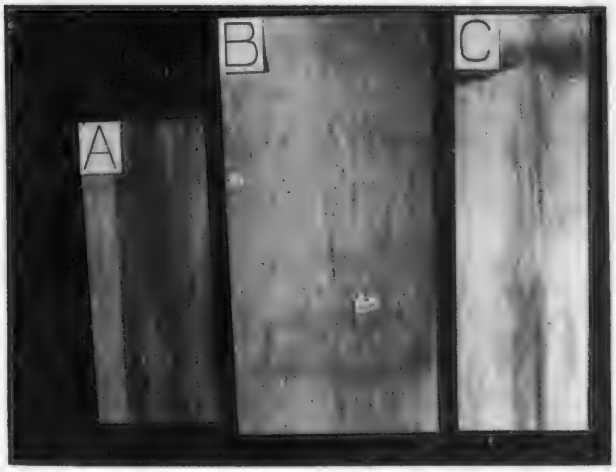

Fig. 2.—(A), Brown stain and blue stain in Sugar Pine sapwood; (B), faint sticker stain in Sugar Pine heartwood; (C), enzymatic brown stain in Idaho White Pine.

Control of Brown Stain in Sugar Pine

WITH SODIUM AZIDE

R. E. Stutz
Research Chemist, Western Pine Association, Portland, Oregon

Brown stain in sugar pine is shown to be caused by a naturally occurring enzyme that can be inhibited by a dip containing 0.5 pounds of sodium azide per 100 gallons . . . Savings of $15 to $20 per thousand can be realized.

THE VIRTUAL ELIMINATION OF degrade caused by enzymatic brown stain in Sugar Pine (PINUS LAMBERTIANA DOUGL.) (Figs. 1 and 2) has been attained by the proper use of the buffered sodium azide dip (1).[2] The first suggestion that this stain was caused by an enzymatic process is to be found in the report and notes of Hubert (2 and 3). He understood the implication of the work of Bailey (4) who clearly demonstrated in 1910 that the brown stain found in the sapwood of some southern and eastern hardwoods is caused by a peroxidase. Nearly half a century later (1 and 5), a peroxidase has been shown to be the cause of the brown stain in Sugar Pine and Idaho White Pine (PINUS MONTICOLA DOUGL.). Had Bailey been aware of the inhibitor, sodium azide, which was later studied by Willstätter and Stoll (6), he undoubtedly would have tested it along with his hot water treatment. That this procedure will prevent brown stain, was later demonstrated by Clark (7) in 1957. Hot water probably was not used because of cost and the fact that it effectively destroys the naturally occurring mold inhibitors. Bailey's work predated the first investigations with sodium pentacholorphenate (8, 9) by 20 to 25 years and the widespread use of the ethyl mercury phosphate (10) by 20 years. Although Hg Cl_2 (mercuric chloride or corrosive sublimate) (11) had been used for a hundred years in suppressing the blue stain fungus and molds that grow on green lumber, and both soda ash and sodium bicarbonate dips had been used for 15 years (11), neither were included in Bailey's study (4). This phase of blue stain control is summarized by Shaffer and Lindgren (12). Effectiveness of alkaline reagents on enzymatic stain can be related to pH inactivation.

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Other Investigations

A number of investigators have studied the so-called chemical brown stain problem in Sugar Pine. Pratt (13) established in 1915 that oxygen and the proper ranges of moisture and temperature were required for stain development. In 1925, an investigator at the California Institute of Technology (14) showed that the replacement of oxygen with carbon dioxide suppressed stain development. This investigator did not use freshly sawn stock throughout the study.

In 1936, the Western Pine Association held a conference on chemical brown stain (3) at which time all aspects of the problem were considered from the means of prevention to the causes. Generally milder drying schedules were recommended for dry kiln operations. In 1940, Rasmussen (15), showed that a higher incidence of stain was found in stock from logs that had been down in the woods for an extended period of time. This could easily be caused by the higher oxygen tensions that would follow partial dehydration or the higher levels of insect damage found in such logs. In a high percentage of such cases, blue stain and brown stain occur together.

The U. S. Forest Products Laboratory (16) re-emphasized the effect of log age and kiln schedules. In 1950, Stout (17, 18) showed that the time stock was held between sawing and kiln drying was most critical. Expeditious handling at this point was recommended. From an enzyme standpoint, the mild kiln schedules tended to minimize the secondary oxidation step in the conversion of the leuco precursor of the stain to the final form. The

[1] Presented before the Wood Drying Division, FPRS 13th National Meeting, June-July 1959; received by the JOURNAL June 11.

[2] Numbers in parentheses refer to Literature Cited at the end of the report.

enzymatic step must proceed the chemical step. In 1952, Millett (19) concluded that the stain was similar in origin to the nonenzymatic browning that occurs in dehydrated food products. This discoloration depends on the condensation of reducing sugars and free amino acids to give a brown substance following well known chemical kinetics. None of the workers studied the possible action of a heat-sensitive or thermal-labile system as was done by Bailey (4) and Clark (7) for the hardwoods.

Common Forms of Brown Stain

Some of the commonly encountered forms of enzymatic brown stain may be seen in Figs. 1 and 2. Sample A in Fig. 1 is an excellent example of brown stain in the sapwood of Sugar Pine. This is the first stage of stain development. Sample B shows the classical form of the stain in the heartwood. The stain has faded out in the sapwood of sample B and not yet developed in the heartwood of sample A. Both samples A and B show white sticker marks where the stain failed to develop—presumably because of low oxygen tension caused by excessive moisture and pressure under the sticker. Sample C shows stain development around shake damage. More general staining was prevented by the azide dip.

Sample A in Fig. 2 is a good example of the simultaneous occurrence of blue and brown stain in Sugar Pine sapwood. The faint sticker stain seen near the bottom of sample B is insufficient to cause degrade. This form of brown stain develops because the moisture level is held high under the sticker for a sufficiently long period of time to permit stain to start to develop despite otherwise good seasoning conditions. This form is common to air seasoning yards. Typical brown stain in Idaho White Pine is seen in sample C. It is most noticeable around the knots and near the pith. It can also be prevented by the sodium-azide dip.

When re-investigation of the problem was undertaken by the Western Pine Association in 1957 (5), it became obvious that there were several major inconsistencies in the accumulated evidence. The time, temperature, oxygen, and moisture requirements for development of the chocolate-colored brown stain that occurs in Sugar Pine heart wood (Fig. 1—B), plus its easily demonstrable thermal lability, suggested enzymatic action. This appeared to be incompatable with the requirements for the formation of the streaked, yellow-brown stain that erratically occurs in sapwood from sour pine logs. (Fig. 3–A).

The pronounced propionic acid odor of sour stock fresh off the saw suggested that this acid was being formed by fermentative processes. After the presence of a massive bacterial infection in the expressed sap from sour stock was established, the correlation was made between stain formation and porosity or the overtreatment phenomena of millwork. When millwork made from sour stock is treated with a toxic water repellent, the preservative is taken up in an uneven manner and often bleeds. This causes unsightly finish discoloration. It results from an emptying of the ray cells by the bacteria.

Examples of porosity and overtreatment may be seen in Fig. 3. In sample A, sour-log stain is seen. Sample B is a furniture part that shows an unequal uptake of a stain dip because of the porosity caused by bacterial action. Sample C is a piece of Sugar Pine that was found in a laboratory survey on trims suspected of over-adsorption because of sour-log stain. This was verified by the use of a solvent-borne dye.

The stain, which may be seen in kiln drying, only develops during the initial stages of the infection and only in areas adjacent to the bacterial activity. The initial invasion route appears to be via the inner bark, and it soon results in rapid infection throughout the length of a 32-foot log.

The odor of a sour log is caused by the formation of large amounts of propionic, butyric, and probably caproic or caprylic acids by the bacteria. The formation of these acids can easily be demonstrated with ninhydrin, after the ammonia salts of the steam distilled acids are separated by ascending paper chromatography on Whatman 3 mm paper with a 20: 2:3 isopropanol: ammonia: water solvent.[3]

Currently, our only method of control is the sprinkled deck or limited storage (6 months) in cold flowing log ponds. Elwood and Ecklund (20) have recently reported on their investigations on the cause and control of this problem.

Experimental Methods

The first step in the study of Sugar Pine was to demonstrate the action of an enzyme by preventing stain development through thermal inactivation. This was accomplished by heating freshly sawn samples individually in polyethylene bags at graded temperatures up to boiling for a 10- to 15-minute period and then rapidly cooling the samples. All experimental samples were either from stock that was freshly sawn out of a sound log or that had been held fresh in the frozen state. Although the thermal results were subject to some variations related to sample thickness, moisture content, method of heating, and the method of sensing the temperature, thermal inactivation occured at about 185° F. after 15 minutes. The inability to stain confirmed the obligate requirement of enzymatic action for stain development. In all stain-formation experiments, the samples were wrapped in freezer paper and held at laboratory temperatures, or in the incubator at 80° F., for the test period, which was usually 28 days.

To stop further stain formation at this level, the samples were dried in the oven at 220° F., after a 4-hour steaming period that accentuated the degree of stain. This reaction, which occurs with heat on drying, is a secondary chemical oxidation of the enzymatically derived intermediate. In air seasoned stock, this leuco pigment will slowly oxidize at room temperature to give stain discoloration.

A thermal response, between 40 and 80° F., can be demonstrated for the rate of this intermediate formation by the enzyme.

The nature of the enzyme was shown in several ways other than the high inactivation temperatures that suggested the action of a peroxidase. The peroxidatic activity of a peroxidase or an oxidase-peroxidase system can be tested with modifications of the purpurogallon procedure. (4,6,21). Dilute peroxidase substrates, such as 0.5 per cent pyrogallo, catachol, or guiacol plus 0.1–0.3 per cent hydrogen peroxide were streaked on thin samples of green wood. The characteristic colors developed in a few minutes in the sapwood areas where the two reagents were overlapped. These thermal and qualitative enzymatic tests were the same as those made by Bailey (4) in 1910 in his investigations on hardwoods.

Although the peroxidase activity can only be demonstrated in the sap wood of Sugar Pine, Idaho White Pine, and Ponderosa Pine (*Pinas ponderosa Dougl.),* purpurgallon activity can be shown in the dialized and centrifuged expressed sap of the heartwood of these species. Dialysis removes both the naturally occurring inhibitors and substrates (21). Although the peroxidase inhibitor responses on green wood samples were not definite with the artificial substrates and hydrogen peroxide, a graded response over increasing incubation periods was found for sodium cyanide, sodium azide, and sodium sulfide over a 0.1–0.001 molar concentration range with the natural

[3] The Western Pine Association is currently supporting a project under the direction of Dr. Elizabeth McCoy of the Bacteriology Dept. of the University of Wisconsin who is characterizing the bacteria and studying its physiology. This information is a prerequisite in the search for a practical and inexpensive way of finding the means of protecting pond-stored logs from this degrade.

Table 1.—DEGRADE LOSS FROM SUGAR PINE BROWN STAIN (BASED ON $20/M AVERAGE LOSS)

lb. Sodium Azide 100 gal. Dip	Degrade Loss $/M Stickered and Kiln Dried Immediately After Dipping	Held in Solid pile 10 days After dipping Then Kiln Dried	Held in Solid Pile 10 Days Prior to Azide Dip - Then Kiln Dried
0	$3.35	$19.90	$11.20
0.27	2.40	1.50	--
0.54	1.38	6.24	--
2.7	5.92	6.13	9.75

All stock was dipped in ethyl mercury phosphate (lignasan) at 2 lb./100 gal. with azide being added as indicated.

Table 2.—DEGRADE LOSS FROM SUGAR PINE BROWN STAIN (BASED ON $20/M AVERAGE FOR 3 YEARS)

Per 100 Gal. Dip Solution lb. Anti Blue Stain	lb. Azide*	Degrade Loss $/M Days in Solid Pile Before Kiln Drying 0	7	14	Air Seasoned 7 months then Kiln Dried
None	0	0.75	$14.36	$19.10	3.90
	0.25	1.82	15.54	9.52	6.08
	0.5	.00	8.41	4.36	0.32
	1	.00	0.49	0.30	.00
12 lb. Penta-chloro-phenate **	0	.36	9.37	16.70	7.76
	0.25	.00	0.95	0.55	0.76
	0.5	.31	0.28	0.15	.00
	1	.00	0.35	.00	0.78
2 lb. Ethyl Mercury phosphate /	0	.62	6.11	4.34	4.47
	0.05	.00	0.51	2.46	.00
	0.25	.00	0.82	0.27	0.13
	0.5	.00	0.25	.00	.00

*Buffered with borax

**Permatox 10-S was used in the field test, / Lignasan

staining system. Hydroxylamine and hydrazine were ineffective as inhibitors. Hydrazine forms the usual orange derivatives with the free aldehydes in the wood. Soluble copper and mercury salts, ethyl mercury phosphates plus sodium pentachlorophenate were inhibitory to lesser degrees. Of the phenols tested, only quercetin was found to activate stain development.

To obtain evidence that the enzyme was not a tyrosinase, the effectiveness of the classical tyrosinase inhibitors was tested over the 0.001 to 0.1 molar range. Stain development was not prevented by para-nitrophenol, 4-chlororecorcinol, or diethyldithiocarbamate. However, [3-parachlorophenyl)–1–1′–dimethylcarbamate) (CMU) and, to a lesser extent, isopropyl-n-phenylcarbonate (IPC) gave fair protection when used in conjunction with ethylmercury-phosphate (Lignasan). CMU and IPC are used commercial as nonselective herbicides.

On the basis of the solubilities in alcohol and water, the chromatographic characteristics, and the adsorption curves of extracts; the stain pigment is believed to be composed of tannins and phlobotanins plus their insoluble and immobile homologues. However, only a small fraction of the color can be removed from brown Sugar Pine heartwood.

Of the effective inhibitors, only sodium azide was considered for use in a stain-controlling dip. It was laboratory tested alone and with the anti-blue stain reagents, penta and ethylmercury-phosphate, with the synergism that is apparent in the field tests being evidenced. On the basis of laboratory tests, an azide, penta, and ethylmercury-phosphate mixture gave the best results in controlling brown stain.

Field Tests

The two field tests were essentially adaptations of laboratory experiments on the mill scale. In both cases, sinker stock was used with 6/4 stock being used in the first test and 5/4 stock in the second test. This stock probably ran in excess of 200 per cent moisture. In the first test (Table 1), the azide levels used were 0.005, 0.01 and 0.05 molar; that is, ¼, ½, or 2.7 pounds of azide per 100 gallons of dip solution. The usual 2 pounds of ethyl-mercury-phosphate preparation (Lignasan) was used per 100 gallons of dip with about 4 M b.m. of mill-run sinker stock going into each package.

In the second field test (Table 2), the highest level of azide was cut to about 0.02 molar, or 1 pound per 100 gallons of dip. Since 48 sample packages of 1–1.2 M b.m. each were required, an effort was made to reject stock that would stain because of log-borne defects, such as shake, insect damage, and rot (Fig. 1–C). A further effort was made to reject these in the grading since, once formed, the leuco pigment is not reduced by azide (Fig. 1–C and Table 1.) Furthermore, in the grading of these samples, only degrade from brown stain resulting from the test was tallied. In the first test (Table 1), brown-stain degrade as such was tallied with no allowances for the log-borne defects.

In both cases, the degrade loss figures (Tables 1 and 2) have been reduced to the $20/M maximum degrade loss, which is the 3 year average loss suffered by one of the companies for Sugar Pine lumber degraded because of brown stain, regardless of the original grade. In Table 3, the percentage distributions are shown for both pieces that were off-grade and for those that had detactable levels of stain (Fig. 2–B) that did not affect the grade.

The first field test (Table 1), was designed to show the sparing action that added azide would have on stain development, and to determine if azide would show any reducing or bleaching action on stain formation that had already been initiated. The samples were dried in two kiln charges with slightly different schedules. At the time that the field test was set up, the full extent of the inhibitory action of ethyl-mercury-phosphate and its apparent synergism with azide had not been clearly established. Because of this favorable synergism, a lower concentration range of azide was used in this portion of the second field test.

The design for the second field test (Table 2) was much more comprehensive. Not only were three concentrations of azide used but evaluation was also made of azide buffered with borax, azide plus penta, and azide plus ethyl-mercury-phosphate under four different handling conditions. For the kiln-dried portion, samples were either stickered immediately or held in a solid package for 1 or 2 weeks before stickering. The samples to be kiln dried were then held for an extra week on stickers. Thus, they were held a total of 3 weeks after sawing before they were put in dry kiln. A normal schedule for sugar pine was used in drying.

The air-seasoned packages were stickered immediately and placed in the drying yard for 6 months, where they were thoroughly exposed to rain before they were dried in the kiln.

The inclusion of the added 2 pounds of soda ash in the buffer system was made after this test. The buffer capacity was about doubled without appreciably altering the pH from pH 9. This gives better regulation of the natural acidity of the stock and thus improves the azide retention by the wood. This alleviated most of the objections from the stacker crews, who were working in enclosed sheds, about the evaluation of hydroazotic acid from sour stock. If the presence of hydroazotic acid becomes noticeable, extra soda ash should be added to the dip. Hydroazotic can be detected by its acetylene-like odor. The use of the lower azide content of the ethyl-mercury-phasphate based dip with at the same level of effectiveness is an alternative. In one operation, where an enclosed stacker is used, stock is held in a solid pile for 90 hours, which alleviates complaints. Presumably, all of the azide is absorbed by the stock.

Recommended Dip

The recommended buffered-azide dip that will inhibit the brown stain enzyme for a 2 week period under

Table 3.—PERCENTAGE OF PIECES GRADED AS STAINED AND WITH DETECTABLE STAIN

lb. Anti-Blue Stain Agent 100 gal.	lb. Azide 100 gal.	Per Cent Graded Stained Days in Solid Pile				Per cent Detectable Stain Days in Solid Pile			
		0	7	14	Air Seasoned	0	7	14	Air Season
None	0	2	73	95	20	45	100	100	57
	0.25	8	67	45	29	42	93	88	53
	0.5	0	45	27	2	6	63	57	30
	1	0	4	2	0	0	23	17	8
Penta (12 lb. Permatox 10-S)	0	8	38	80	36	31	78	100	51
	0.25	0	3	2	3	59	47	41	19
	0.5	1	2	2	0	53	30	15	10
	1.0	0	2	0	3	55	16	5	48
Ethyl Mercury Phosphate	0	6	25	21	23	21	61	55	46
	0.25	0	1	9	0	25	33	31	60
(2 lb. Lignasan)	0.25	0	5	2	1	15	24	16	47
	0.5	0	2	0	0	5	4	8	9

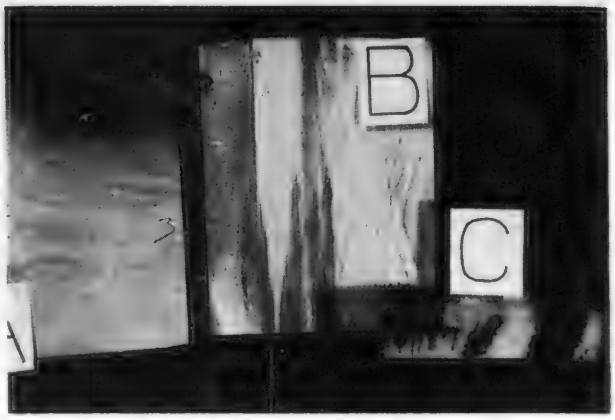

Fig. 3.—(A), Sour-log brown stain in Ponderosa Pine sapwood; (B), porosity and overtreatment in a partially finished furniture part—resurfaced to show the unequal uptake of a stain dip used in finishing; (C), Sugar Pine trim from laboratory-porosity test with a solvent-borne dye.

most anticipated operating conditions at about 15–20c/M is as follows:

0.5 lb. sodium azide
3–4 lb. borax
2–3 lb. soda ash
100 gal. water

If danger from blue stain or surface molds exist, an added 3 to 5 pounds of sodium pentachlorophenate may be added. If blue stain does develop in undipped stock, there is very high probability of brown stain in the sapwood (Fig. 2–A). If the ethyl-mercury-phosphate, anti-blue-stain dip is preferred, the azide level can be reduced 50 per cent, as was done in the second field test (Table 2). This dip mixture was not originally recommended because there has been some concern over the possible dangers from mixing the two reagents. This danger can not be demonstrated in the laboratory and is highly unlikely with the dilute alkaline solutions used. Because of the cost advantage, lower azide level, and a lower level of hydroazotic evelution from sour stock; this point is being resolved by in-use experience. Several mills are currently using this system effectively.

Since sodium azide is a toxic reagent, as are the anti-blue-stain chemicals, normal precautions must be taken in the use and handling of mixtures containing azide. Rubber gloves, adequate ventilation, personal cleanliness, and good housekeeping are requisites for the use of azide as well as the anti-blue-stain dips. The handling hazard from azide is not greater than for penta. As a further precaution, the solutions should be mixed in a wooden, black iron, or galzanized tank. Lead and copper tanks and fittings should be avoided. The state of California has certified the use of azide as recommended (1).

The question has been raised concerning the advisability of using shavings from azide-treated stock for poultry bedding. This has been investigated for chickens. No harmful effects could be shown in a feeding test; in fact, the birds on azide-treated shavings gained weight slightly faster than the control birds beded on azide-free shavings. (22)

Discussion

In the first field test, (Table 1), the data clearly indicated that sodium azide will decrease the brown-stain degrade losses. The anticipated response gradient did not develop completely, however, because of the higher level of defective stock included at the 0.5 and 2.7 lb./100 gallon azide concentrations. The inability of azide to reduce or bleach the stain that had already developed during 10 days in a solid package was also demonstrated. Since these two packages contained mainly sound stock, the differences seen between the azide-treated and the untreated samples is evidence of the protection that the azide exerted on the stock during the 3 days it was awaiting kiln drying and during the period that it took the stock to reach inactivating temperatures in the kiln.

The second field test (Tables 2 and 3) verified the conclusions drawn from the first test as to the effectiveness of azide. It also supplied the first conclusive field evidence of the suppressing effect of both penta and ethyl-mercury-phosphate on brown stain. The test results were particularly gratifying for the section that was held in a solid pile 2 weeks and experienced a total of 3 weeks off of the saw before entering the dry kiln. The results of the air-seasoned section followed the same pattern except for the exceptionally low level of degrade seen in the untreated control. The air-seasoned samples showed a tendency for stain to be concentrated in one end of the boards. This was believed to be related to pile orientation in the dry yard, although it may have been caused by rain washing or non-uniform air drying.

Those mills that used azide as directed during the 1958 season found it very effective in controlling enzymatic brown stain. The inclusion of added soda ash to the buffer system has improved these results.

In Table 3, the percentages are tabulated for each of the sample packages in the second field test for degrade because of stain and for detectable levels of stain not generally attributable to log-borne defects (Figs. 1 and 2). This last limitation can be somewhat difficult to judge when the secondary effects of fire damage and pitch pockets are considered. In this second consideration, the graded respones of increasing azide concentration in relation to stock handling is seen. In several of the packages, every board was stained. Also, there are the usual apparently unexplained aberrancies as is seen in the penta-plus-azide samples that were stickered immediately and also with the highest level of azide and penta in the air-seasoned section. In retrospect, this appears to have been caused by failure of the buffer system. Increasing the buffer capacity by the addition of soda ash to the borax system should improve the results. Even with proper dipping, however, azide does not permit gross mishandling.

The reproducible laboratory results that anticipated the field test were possible only because the stock used was strictly fresh. This was achieved by chilling it out at the mill before transporting it to the laboratory where it was held in the frozen state. Under hot humid conditions, evidence of stain may be demonstrated in a single day off of the saw.

The laboratory data indicated that the thermal-labile system was a per-

oxidase by virtue of its responses to peroxidase substrates and its inhibition by the heavy metal enzyme inhibitors—cynaide, sulfide and azide. Mercury-ethyl-phosphate probably also inhibits by acting with the active heme portion of the enzyme, while the penta inhibition is competative at the substrate level. The formation of ethyl-mercury-azide could account for the apparent synergism seen between azide and ethyl-mercury-phosphate. Since the pH vs. activity response is very low for most plant peroxidase (21) at pH 8.5–9.5, the added soda ash would further suppress stain development.

The normal function of this hematoporphyrin enzyme has not been demonstrated, but in all probability it does not normally form a multiplicity of oxidized phenolic products. This is common for peroxidases in unphysiological situations (21,23). It could be a protective mechanism as the formation of tension wood that has been reported to be related to peroxidase activity in eucalyptus (24). More likely, it normally functions as a dehydrogenase (23, 25, 26), perhaps in lignification. The abnormal oxygen levels that occur on sawing, or after shake or insect damage, permit the secondary activities of the peroxidase to become apparent. This is also the case when fruits and vegetables darken on peeling.

The first report of the bonus derived from the faster kiln schedules made possible by the use of buffered azide on Sugar Pine was presented by Knight (27). Starting temperatures of 160° F., now in use in some cases, have replaced the former starting temperatures of 120° F. or even less. A 20 to 30 per cent savings in kiln time is possible with no seasoning difficulties. This improvement is possible because of the higher transfusion rate occurring at these temperatures.

Conclusions

Greater flexibility in handling, with better seasoning both in the dry kiln and air-seasoning yard are possible within definite limits by using the buffered azide dip at about 16c/M. The inclusion of the blue stain controlling chemicals at a cost of about 40c/M for chemicals is only necessary under conditions when there is a danger from this stain, such as in the air yard or when an extended delay will exist prior to kiln drying. The dip will permit more effective use of the dry kiln, since the drying rate will be limited by the other seasoning defects and not by brown stain. This will permit speeding up the schedules, higher initial wet-bulb temperatures, and the use of better lumber-conditioning procedures. The capacity of the equipment and degrade from other defects will set the limits.

The disappearance of the stain from the sapwood of Sugar Pine and both the heart and sapwood of Idaho White Pine can be attributed to the lower levels of the natural substrate and inhibitor (Figs. 1 and 2). The stain appears in the sapwood, and then it disappears because of further oxidation of the pigment precursor by the enzyme. The apparently higher enzyme level, coupled with a lower natural substrate level, may account for the disappearance of the stain from the heartwood of Idaho White Pine. Brown stain is never as severe in this species as it is in Sugar Pine. The slowness to develop and the greater intensity of stain found in Sugar Pine heartwood can be related to higher levels of both the natural inhibitor and substrate. Since peroxidases are activated by phenols and enzymatically derived phenolic products, enzyme activation does not appear as important as inhibition in regulating the observed responses.

The high level of phenols present in lumber, the preference of the peroxidases to oxidatively break down phenols, and the apparent tannin like nature of the stain pigment indicate that non-enzymatic browning (19) is not involved. The action of peroxidases on sugars is to convert them to their corresponding sugar acids and on amino acids to form aldehydes. Reducing sugars and free amino acids are required for the browning reaction. If the browning reaction was the primary cause of brown stain, azide inhibition would not be effective.

The coffee stain (28) found in the Northern White Pine, *Pinus strobus L.*, should be controllable with the buffered azide dip. Also if buffer control is maintained around pH 8.5 on the surface of the stock, satisfactory results should be obtained in controlling the enzymatic stain that develops in the hardwoods (4, 7) and redwood (29). However the stock must be treated fresh off the saw, and, in the case of the hardwoods, the entrance of air through the large xylem ducts after falling may be sufficient to raise the oxygen tension to the level that will permit peroxidase activity.

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Fastener Design and Cost

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Three points to remember: Consider the cost of the fasteners in the assmbled product, not at the purchasing agent's desk; watch for labor savers. Make each part of the fastener work—the head, the thread, the point. Consult fastening specialists to reduce assembly costs, improve your product.

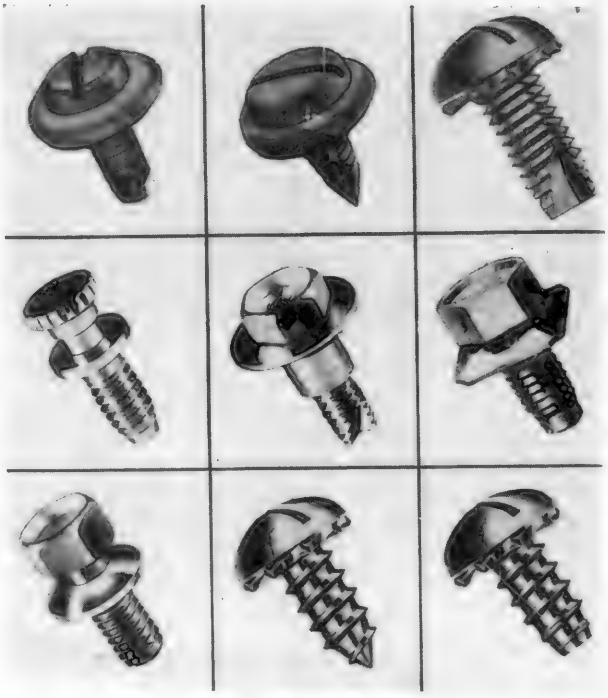

Fig. 1.—Special sems.

COSTS ARE GOING UP across the board . . . on material, wages and burden, as shown in Figs. 2a and 2b. Both curves have kept the same inclination, and there are no indications that this will change. Since we must live with these increasing costs, then we should strive for greater production efficiency to hold the line on costs.

It is interesting to see where fasteners fit into this general economic picture. Fasteners are low-cost components that range in price from $3.00 to $6.00 per 1000 pieces, or about 1/3 to 1/2 cent apiece. The *cost* per 1000 fasteners, however, is a completely different story. By the time these 1/3 or 1/2 cent fasteners reach the shipping dock installed, their cost has increased to 2 or 3¢ each. The difference is installation, labor and overhead (Fig. 3).

The greatest opportunity for savings in total fastener cost, then, is in the application or installation of fasteners. A 30 per cent savings in installation time—greater production efficiency—will more than offset the entire purchase price of the fasteners.

How do you cut down on installation time? Analyze the following questions carefully:

1. Is the fastening necessary?
2. Is the minimum number of fastenings specified?
3. Does the fastener specified perform the job best?
4. Is the fastener simple to apply?
5. Does the fastener have the proper specifications for material and finish?

Now, look at some design details of one of the most common of all fasteners—the screw.

The American Standard for Wood Screws (ASA B18.6.1—1956) in our opinion has not kept pace with today's requirements. While it lists only three head styles, the tapping screw standard has eight, and there are many more useful head designs from which to choose. The screw threads in the Wood Screw Standard are based on cut threads, but rolled threads make stronger, better threads and are being used more frequently in wood products all the time. The screw point is undefined. Let us take a closer look at these three parts of a screw:

The Head

The head has three functions. Its first job is to tighten the screw. There is the slotted head, the oldest and most popular although not the best, and the cross recess head, a better but more expensive type. Hexagon and hexagon washer heads are the most practical head designs and are fast finding more use. These types are shown in Fig. 4. Hexagon head styles—when driven with magnetic socket bits—assure good, fast assemblies with low tool maintenance cost. An extra head slot for the "do-it-yourselfer" without a socket is generally furnished by the manufacturer without charge.

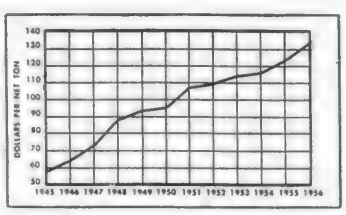

Fig. 2a.—Finished carbon steel arithmetical price composite.

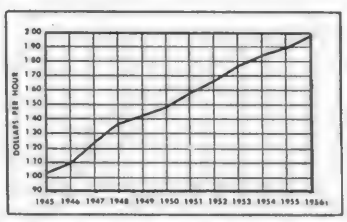

Fig. 2b.—Hourly earnings of production workers in manufacturing industries.

[1] Presented at the Fall Meeting of the Northeast Section, FPRS, held Oct. 30-31, 1958, in Lancaster, Pa.

The Author: Fred Knohl graduated in mechanical engineering from a university in Germany. He joined the Illinois Tool Works about 30 years ago as Chief Engineer of the Shakeproof Div., and for the past 15 years has concentrated his activities there as a consultant engineer.

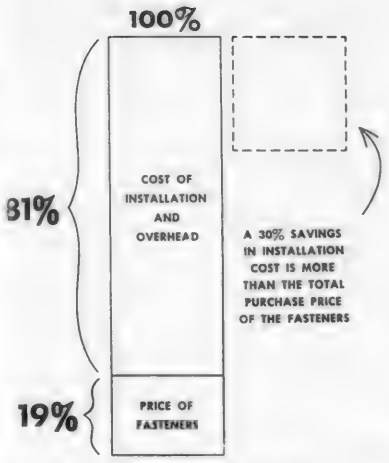
100%
81%
COST OF INSTALLATION AND OVERHEAD
A 30% SAVINGS IN INSTALLATION COST IS MORE THAN THE TOTAL PURCHASE PRICE OF THE FASTENERS
19%
PRICE OF FASTENERS

Fig. 3.—Relative cost of installation and overhead as compared to price of fasteners.

The second function of the head is to provide a bearing surface sufficiently large to prevent the screw from sinking into the surface under use. Many washer-head styles are available to satisfy this requirement. Separate washers should be considered only when it becomes impractical (because of size) to cold forge the washer as part of the head. If washers are needed, it is best to order them pre-assembled to screws, in order to keep hand-assembly costs down and assure proper use. Almost any type of washer—flat washers, lock washers, spring washers, crating washers, finishing washers—can be automatically assembled to screws. These are known as Sems shown in Fig. 1.

The third function of the head is to provide a braking action for the driver, a safety feature to avoid stripping the screw thread in the wood. This is accomplished by "nibs" under the head, and this type of screw is called a "NIB-SCREW" (Fig. 5). The protrusions

g. 4.—Types of screws showing slotted, Phillips, and hexagonal heads.

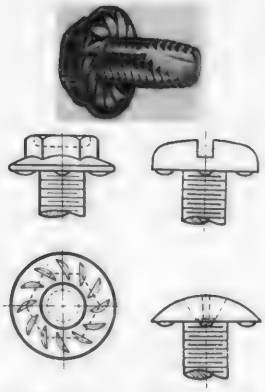

Fig. 5.—Nibscrews increase stripping torque, eliminate screw stripping.

embed themselves into the top plate and reduce excessive driver torques. Generally, they build up the stripping torque to four times that of a plain head screw. In the past when most articles were made up of hardwood of heavy sections, there was little need for this design. Today's products, however, use thin sections and particle board, and the Nibscrew feature becomes a necessity. For example, a No. 6 screw driven into a ½-inch section drives with 4 inch-pounds of torque and strips at 10 inch-pounds. There are no power tools available that will work to such fine settings, so the screws strip from overdriving and the pull-out strength drops to nearly zero. By comparison, Nibscrews provide a stripping torque of 40 inch-pounds rather than 10, and permit a driver setting of 25 inch-pounds without failure.

The measurement of torque is new to the wood products industry, and deserves comment here.

One model of a torque-testing fixture is shown in Fig. 6. Its function is to determine the torque-holding strength of screws. There is a mounting plate for the assembly, and an adapter to apply a torque wrench in such a fashion that it will show the applied torque reliably. The proper method is to use all the components of an assembly—the screw, the piece to be mounted, and the work piece. The test is not valid if only the screw and the work piece are used.

Fig. 6—A torque-testing fixture. Manufactured by the P. A. Sturtevant Co.

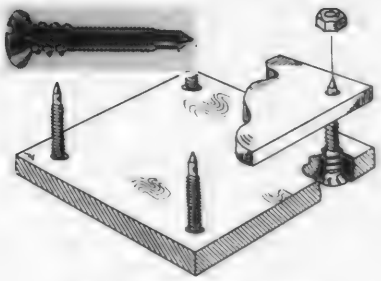

Fig. 7.—A mounting screw.

All three aspects of screw-head design have a definite bearing on total costs, so it is well to consider these facts when selecting screws.

The Thread

The shank or threaded part of a screw can also do double duty. In the form of a mounting screw, it consists of a larger left-hand section just under the head and a smaller right-hand section to follow (Fig. 7). When the screw is driven left-handed into a board or rail, it anchors itself in the fashion of a stud. The use of this part quite often eliminates the need of extra nuts or tee nuts, and simplifies many assemblies. A typical application is the leg mounting on upholstered furniture.

In regard to the range of shank diameters, it appears that No. 7 and No. 9 screws do not offer enough advantage in holding strength to be kept active. As for shank lengths, the many increments should be reviewed to keep inventory requirements low. Pull-out tests made on various woods show that ⅛-inch length increases have little effect on performance.

The Point

The point of the screw should also be used to the best advantage. The Type 17 Screw, shown in Fig. 8, has a drill point that eliminates the need for pilot drilling. This costly operation quite often is done at the assembly station with hand power drills, and time studies reveal that the cost is approximately ½¢ per hole (or $5.00 per 1000) in labor and overhead, plus

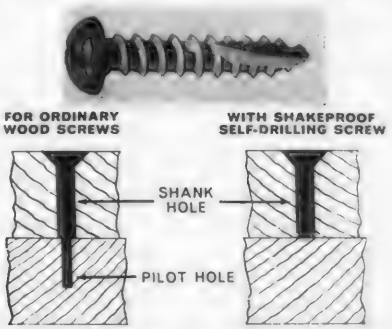

Fig. 8.—A "Type 17" screw, which drills its own hole, eliminates pre-drilling.

tool and bit maintenance. The sharp cutting edge of the Type 17 Screw point drills the proper hole for the screw and actually taps the wood without crushing the fiber, thereby increasing the holding strength.

The tapered point of the screw generally is a very desirable feature for hole finding, although it is a detriment in some applications and should be eliminated. As an example, consider the fastening of the leg mounting plate to a table top, where pre-drilling is required because of the brittleness of the particular type of particle board used. The best fastening method is to put a counterbored hole in the material, and use a screw without a point (Fig. 9). The counterbore will guide the screw into the hole, and the screw will act like a bottom tap. It uses the valuable end threads for holding, and backs up the starting thread with 1/16 solid material.

Consider the screw point. Make it work for you, and it will help brighten your cost picture.

Material

In the past, most steel screws used in the wood industry have been made of soft steel. In hardwood such as maple and oak, the soft screw generally fails before the wood section. Manufacturers should seriously consider changing to heat-treated screws for several reasons. From a cost standpoint, it takes only a very small percentage of screw failure (at today's labor rates) to justify the extra price of heat-treated screws. From a performance standpoint, a heat-treated screw will not burr the driving slot, ream out the Phillips recess, or break half a flat head section as soft screws often do.

Finish

Screws should be protected against rust in shipping and storing. Here again, the oxidized surface of a hardened screw stands up against corrosion much better than a soft steel screw. If protective finishes are required, either cadmium- or zinc-plated parts are adequate. Recently, the dichromate dip over these finishes has become so popular that most screw companies supply it without additional cost, but you have to ask for it. In salt-spray tests, the dichromate finish generally doubles the life of protection. Also, it is often used as a decorative finish to replace the statuary bronze Old English or Copper oxidized finishes, which cost much more and have very low corrosion resistance.

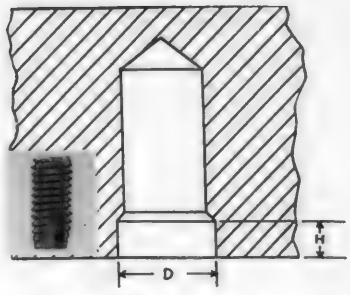

Fig. 9.—A counterbored hole.

In conclusion, these are the points to remember:

1. Consider the cost of your fasteners at your shipping dock, not at the purchasing agent's desk. A savings of 30 per cent in installation time will more than pay for the fasteners themselves, so look for labor-saving fasteners.

2. Make every part of the fastener work for you, the head, the thread, the point, and so forth. Consider updating standard practices by taking advantage of new designs.

3. Consult fastening specialists to reduce your assembly costs and improve your product. This service is available without charge.

LOCALLY PRODUCED HARDWOODS FOR Small Building Construction[1]

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New York farmers use 75 million board feet of locally produced lumber annually —much of it hardwood. To promote and increase the effective use of hardwoods in construction of small buildings, a simple method of selection for strength is needed.

HARDWOODS PREDOMINATE in 84 percent of the 12,000,000 acres of New York commercial forest land, of which about 3,500,000 acres are found on farms (2). A recent survey (4) indicates that northeast farms annually use about 1500 board feet of lumber, of which it is estimated that at least 35 percent is dimension lumber used for farming. With over 100,000 farms in the state, New York farmers are using approximately 150,000,000 board feet of lumber annually. Well over half of this is locally produced, and a considerable amount is hardwood lumber.

Extension agricultural engineers continually are asked for advice about the size and spacing of structural members. This information is available for stress graded lumber and can be provided readliy. In many instances, however, this information is far too conservative. When locally produced lumber is used, it is necessary to rely on experience and judgment rather than on the findings of research.

Safe Working Stresses Needed

Farmers will continue to use locally produced non-stress graded lumber as long as they have their own woodlots or they can buy it readily at an attractive price. It will not be used effectively in small building construction, however, nor will its use be increased unless we develop a simple method of selection for strength. This method must be such that it can be easily and rapidly applied on the construction site by untrained people. There is not sufficient continuous volume at most local sawmills to justify the employment of a competent grader. In fact, many of the mills do not operate continuously. Much of the hardwood dimension lumber being used in small buildings comes from inferior logs or from the hearts of high quality logs from which as many good boards as possible have been removed. The conventional method of arriving at working stresses will not usually be practical for this

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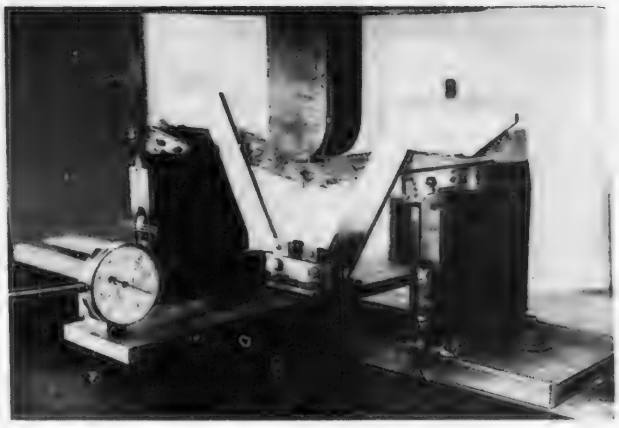
Loading apparatus for determining modulus of rupture of full size test specimens.



Loading and measuring apparatus for testing clear wood specimens cut from full size test specimens.

material, therefore a method suitable to this type of material and its use must be adopted so that working stresses that are both safe and realistic can be arr ed at.

A study has been made by the Northeastern Forest Experiment Station, the U. S. Forest Products Laboratory and the Agricultural Research Service to evaluate the properties of log-run dimension lumber being used in farm buildings in the northeast. A somewhat similar study is being conducted in New York at this time with the assistance of the Northeastern Forest Experiment Station and the U. S. Forest Products Laboratory. A portion of this study has been completed and is reported by Dirksen (1). The appraisal was made by randomly selecting and inspecting a quantity of log-run lumber at several mills. A strength ratio was assigned to each piece and some of the pieces were tested to determine the accuracy of assignment. A frequency distribution of the strength ratios was combined with a frequency distribution of clear-wood strength to give a product distribution of estimated modulus of rupture. Frequency distributions of other variables, such as size deviation, may also be included in the product distributions. The method is described fully by Wood and Tasker (7) and by Dirksen (1).

Selection for Strength

Hardwoods have an apparent strength advantage over softwoods on the basis of clear-wood strength. However, data from the current study show that this advantage can not be utilized in building construction unless there is some selection. Fig. 1 is a cumulative product frequency distribution for 2 by 6's of oak and hemlock. Only when the 3 percent level is reached does the expected strength of oak become equal to that of hemlock. Data presented by Wood and the U.S. FPL (4, 6) for 2 by 8's show oak to have a greater expected strength at all levels but not sufficiently more at the low levels of probability to justify different design values.

The study also includes maple, beech, and elm as well as the 2 by 10 size of all species. In addition, the ability of farmers and farm carpenters to reject pieces of low strength is being evaluated. These data will be included in a product distribution along with strength ratios, clear-wood strength, and size deviation to give the expected strength of pieces that actually will be put into use. Such a product distribution will exclude a portion of the lower strength ratios that will be rejected in the selection process. Some study must also be made of the amount of material that reasonably can be rejected for use in bending but that can be utilized in other ways.

The procedure for determining a working stress would be to select a desired probability after which the expected modulus of rupture would be multiplied by the appropriate factors for duration of load, safety, and other

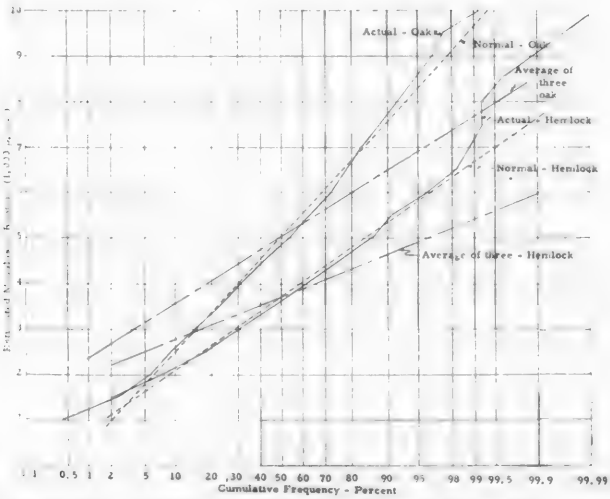

Actual - Oak
Normal - Oak
Average of three oak
Actual - Hemlock
Normal - Hemlock
Average of three - Hemlock
Cumulative Frequency - Percent
0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.99

Fig. 1.—Product distributions of oak and hemlock 2 by 6's; includes strength ratio, clear-wood strength, and size deviation.

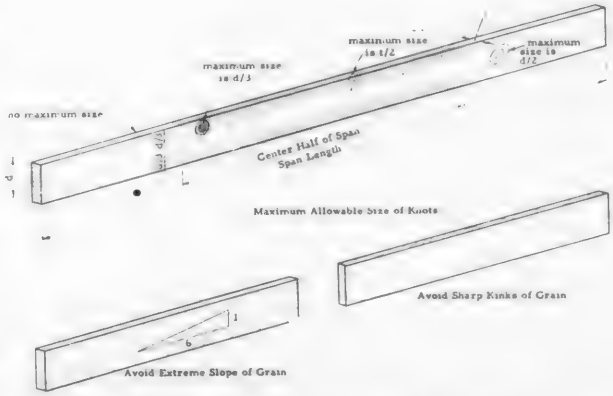

maximum size is d/3
maximum size is t/2
maximum size is d/2
no maximum size
Center Half of Span
Span Length
Maximum Allowable Size of Knots
Avoid Sharp Kinks of Grain
Avoid Extreme Slope of Grain

Fig. 2.—Selection rules should be well illustrated.

factors. Variability of clear wood has already been included in the most logical manner in the product distribution. This gives one grade of lumber, the lower limit of which is determined by the amount of material that reasonably can be rejected. The probability level is then chosen by the designing engineer. Engineers and architects should no longer hesitate to design with locally produced lumber. In addition, the inherent strength advantages of the hardwoods can be utilized more fully.

Should the above method not prove feasible, Wood and Ostrander have suggested a method for the design of farm buildings that should receive consideration. They propose basing the design on the expected average strength of three adjacent members. Normal distribution curves for such a condition are shown in Fig. 1. The justification for such a procedure is that in most farm buildings the framing is exposed so that impending failure may be detected easily and the damaged member replaced. In addition, loads on rafters and joists are distributed to adjacent members through the roof deck or floor and bridging. This procedure could be followed with or without selection of the lumber.

Rules for Rejection

A suggested general rule for rejection of low strength pieces might be stated as follows. Reject for use as rafters, joists or built-up girders, all pieces of lumber having: (1) knots or knot holes at the edge of the wide face and in the center half of the length which are greater than 1/3 its width; (2) knots or knot holes elsewhere in the wide face which are greater than one-half its width; (3) knots in the narrow face of pieces containing the heart center (pith) of the tree and in the center half of the length which are greater than one-half its thickness (no limit elsewhere in the narrow face); (4) cross grain or sharp kinks of grain sloping more than 1 inch in 6 inches of length; (5) evidence of rot; and (6) a reduced cross section. A set of selection rules should include photographs or drawings similar to those in Fig. 2.

Suddarth (5) has established selection rules for hardwood lumber for structural nail gluing or other specialized structural uses. These rules conform with the National Hardwood Association stress-grading rules for 1450f grade joists and planks for spans up to 16 feet with the exception of allowances for end checking. Such rules are very useful for prefabricators, but they are not applicable to construction site selection by untrained personnel.

Design of Joints

Research is also underway to define the rigidity of timber joints. For several years, rigid frame and semi-rigid frame design methods have been used with concrete and steel. These methods result in more effective use of steel and concrete, and they could be applied in wood design, provided moment-rotation relationships of timber joints can be defined. The American Institute of Steel Construction has supported extensive research to establish the moment-rotation relationships for many of the standardized connections for steel. In addition, extensive investigations have been carried on in Great Britain. Wood construction has few standardized connections, and most of these are not designed to provide resistance to rotation. For this reason, attempts are being made to develop a general relationship from which the most desirable joints can be planned and utilized. It is difficult to determine whether or not this method of can be utilized for other than prefabricated buildings because of thelack of quality control in on-the-site construction. If semi-rigid frame design can be used, hardwood dimension lumber will be considered favorably, Preliminary results of studies on nailed joints show that hardwood resists rotation better than softwood lumber of approximately the same density. Also, the prefabricated business is expanding rapidly, and hardwoods will likely find their place in many of the local shops.

Minimum Members

Labor is a major construction cost so the design should call for the least possible number of members. This can be accomplished by using the deepest members and the highest possible design stress. Most locally produced hardwoods are rough sawn, which gives them a cross-sectional advantage over surfaced lumber. At any given design stress, an S4S piece has a load-bearing capacity of less than 75 percent of that of a piece at full dimension. Some of the surfaced pieces presently on the market are even more undersized, with a load-bearing capacity of not more than 60 percent of the capacity of a full-dimension piece. This cross-sectional advantage means that rough-sawn lumber can be designed at a lower working stress and still have the same total load-carrying capacity. For example, full-dimension oak at 1,500 psi. would be as good as surfaced Douglas-fir at 2,000 psi., and the oak can probably be purchased at a considerably lower price. Hardwoods also have an advantage over softwoods because their better strength characteristics frequently allow the use of a smaller size. This is particularly true of the situation where hardwood 2 by 10's or softwood 2 by 12's would be required, because it is difficult to find logs which will make good 2 by 12's. In addition, the study served to emphasize the superior failure characteristics of oak compared with hemlock. The oak is tougher and gives considerable warning of impending failure, which is slow and progressive. Hemlock appears brittle, and it fails suddenly and completely with little or no warning.

Joists and girders on which heavy loads are imposed for a long duration are the most advantageous uses for hardwoods in small buildings. Some hardwoods also make excellent floors. The present trend to one-story, clear-span farm buildings using trussed rafters, roof trusses, and rigid frames provides additional uses. Agricultural engineers at Oklahoma State University has found that small trussed rafters can be fabricated satisfactorily of one-inch rough lumber. Roof trusses are usually fabricated with metal connectors that require the use of mechanical tools and eliminate nailing problems. Wood purlins, which are bolted in place, are used with some of the prefabricated steel frames.

Summary

In summary, it must be recognized that hardwood lumber will have limited use for small building construction. Much of that which is used will not be of the best quality, because it will be sawed from the heartwood of high-quality logs or from lower quality logs of the most desirable species. The most important objectives should be to develop ways to use *all* locally produced lumber most effectively. This will involve the use of simple selection rules and an evaluation of the lumber which is being produced. A cooperative effort will hasten the accomplishment of these objectives.

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Articles are listed in three ways: by title, by subject and by author. Title and subject listings are combined and appear first. The title of each article (omitting only the articles "a", "an", and "the") is indicated by the presence of authors' names in the Title and Subject Index. In addition, each article is listed under one or more subject headings. Categories of subjects, in boldface type, reflect terms in current usage.

The Author Index contains an entry for every author. For articles with a single author, the listing gives author's name, subject, issue number, and page. For articles with two or more authors, the listing for the first author gives all authors' names, subject, issue number, and page; listings for co-authors refer back to the first author. Two or more articles by the same author are listed chronologically.

If the title, subject matter or an author's name is known, an article can be located quickly. If neither is known, there are many clues by which an article can be found. For example, an article on high-temperature drying of birch may be found under both Seasoning and Birch.

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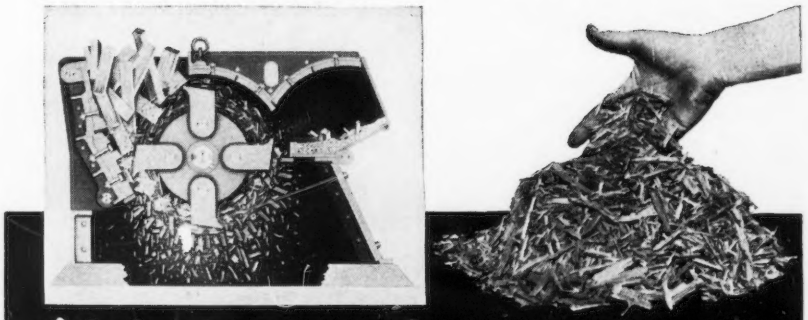

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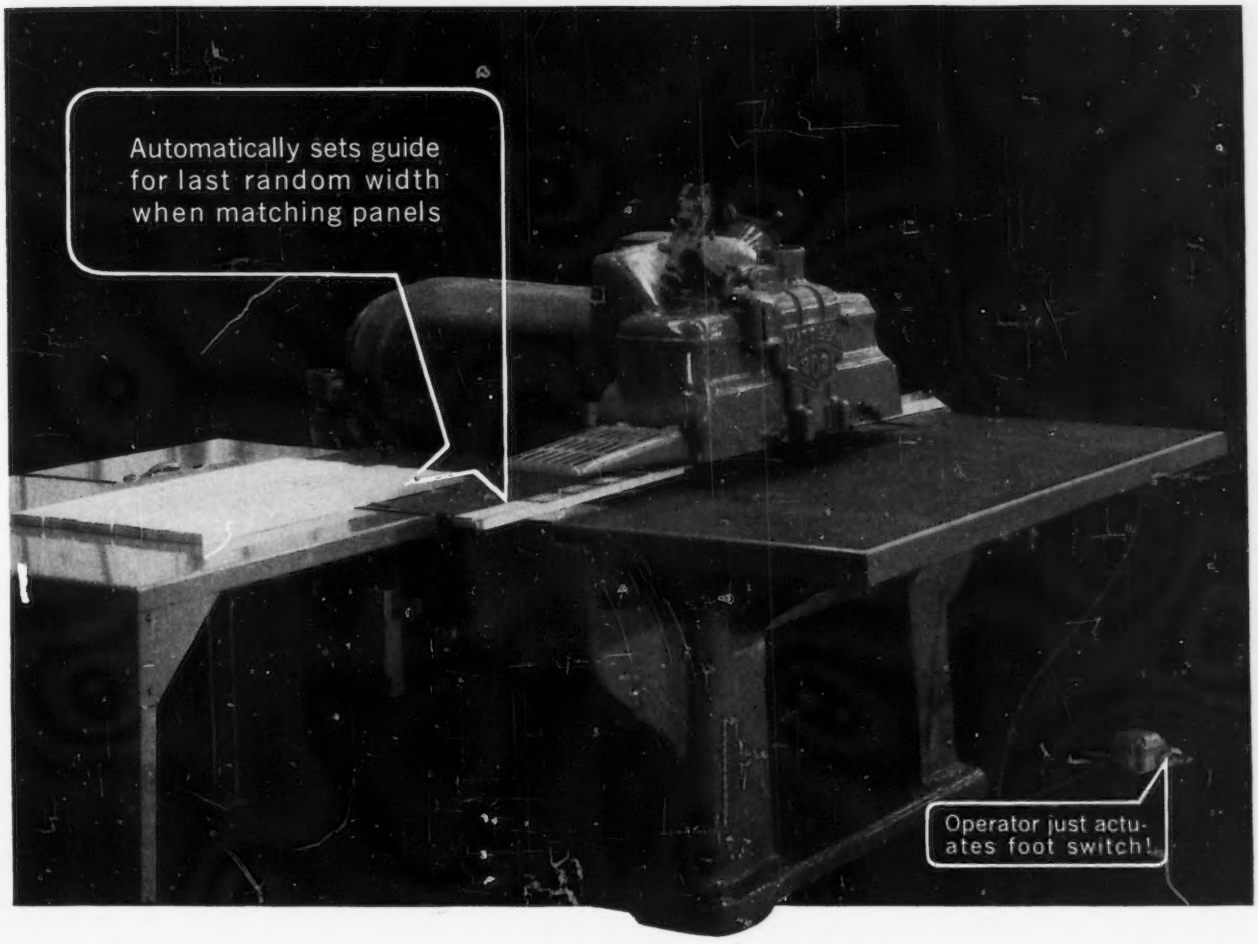

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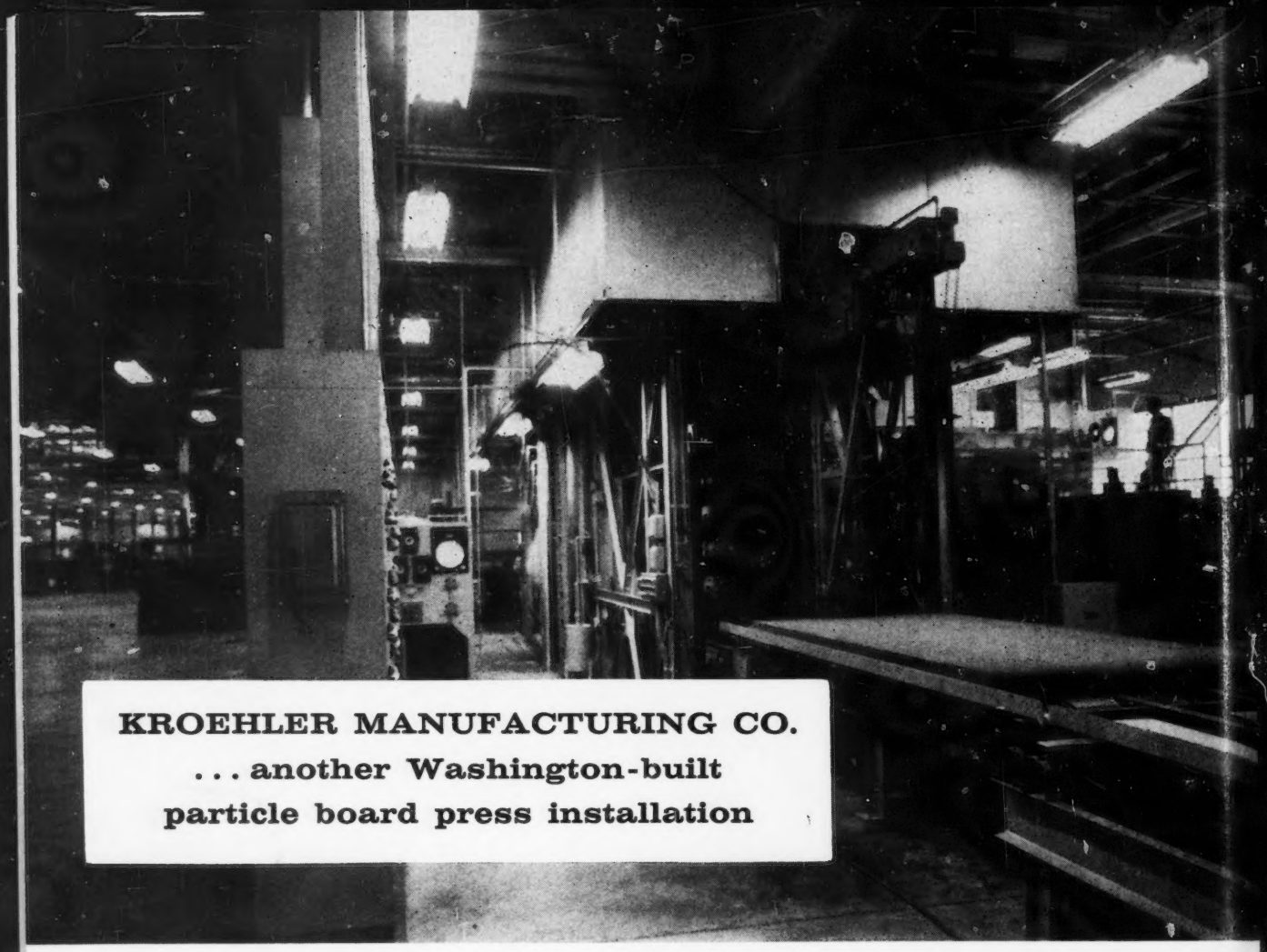

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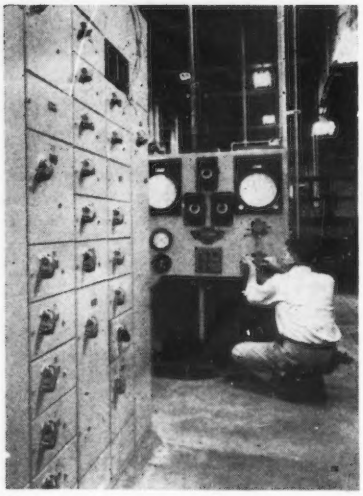

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